A
[HAN]DBOOK OF BOTANY FOR INDIA

BY THE LATE

K. RANGACHARI, M.A., L.T.,
Indian Agricultural Service

REVISED AND ENLARGED

BY

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PREFACE TO FOURTH EDITION

THE authors are glad to bring out this Fourth Edition. The most important change is in respect of presentation in that suitable paragraph headings and summaries are added. Line drawings and diagrams have been newly inserted. The book has been condensed in some chapters so as to make it handy and suitable to the junior students.

COIMBATORE, *14th July 1948.* — S. N. CHANDRASEKHARAN. S. V. PARTHASARATHY.

PREFACE TO THIRD EDITION

IN Arts, Science and Professional Colleges, Botany is gaining increasing importance. It is but natural in an agricultural country like ours, everyone, whether directly connected with Agriculture or not, must know the essentials of plant life. Therefore, the demand for a suitable hand-book of Botany became imperative and the original author of this text-book, the late Dewan Bahadur K. Rangachariar took initiative as early as 1925 in writing up what may be said to be the first text-book with Indian examples. The book was revised in 1940 and again now, especially in view of the changes in syllabus and also due to advancement of our knowledge in new branches, such as Genetics, which are gaining increasing importance in the teaching of Botany in Colleges.

In this edition, "Fungi and Bacteria" have been revised and enlarged. Chapters dealing with "Economic Botany" and "Elements of Genetics and Plant Breeding" are new additions. Chapter XXVIII dealing with "Description of Families" has been enlarged by the addition of more families. With reference to Chapter XXV, I wish to mention that only bare elements of Genetics and Plant Breeding have been included here, as I am afraid that any attempt to present the subject in any greater detail may make this edition unwieldy. Further, a separate volume on the subject is under preparation by me.

I wish to express my thanks to my Assistant, Sri S. V. Parthasarathy, B.Sc.Ag., M.Sc., for help rendered in the preparation of Chapter XXV. I also thank the Publishers, Messrs. P. Varadachary & Co., for having requested me to revise this text-book.

Agricultural College and Research Institute, Coimbatore, 4-4-1945. — S. N. CHANDRASEKHARA AYYAR, *Lecturer in Botany.*

PREFACE TO THE SECOND EDITION

THE demand for a suitable hand-book of Botany became imperative with the place assigned to it by the Universities in the remodelled courses. The author is glad to learn that the first edition of this book has met the requirements of the University students, whether in Arts and Science Colleges or in professional Colleges. A revision of the book has become necessary, especially in view of the changes in the syllabus in Botany. The author has taken advantages of this opportunity to make a slight rearrangement of matter here and there so as to emphasise clearly the relative importance of the different facts. He has also found it desirable to introduce fourteen families in "Chapter XXIII Angiosperms" and their characteristics are given in full in their respective places. The author trusts that the inclusion of the scheme of classification adopted by J. Hutchinson of Kew will be welcomed by students interested in systematic Botany.

PREFACE TO THE FIRST EDITION

THE number of students studying Botany is gradually increasing. Books on botany now in common use are not suited to the requirements of the Indian student, as the plants referred to in many of these books are foreign ones not known to him. The few books in which Indian plants are dealt with cover only certain aspects of plant life, and too much prominence is given to the study of Natural Orders or Families.

This book is intended to meet the requirements of University students in their Intermediate and pregradutae courses and those of the professional Colleges such as the Medical, Agricultural and Forest Colleges. It will also be found useful to persons interested in the study of plants. The scope and arrangement of the topics adopted is based upon my experience as a teacher and examiner for the Madras University Examinations for nearly a decade.

I have to express my thanks to Mr. Rudolph D. Anstead, Director of Agriculture, Madras Government, and the Government of Madras for giving me permission to reproduce the illustrations mentioned below from my published books) Figs. 4, 11, 13, 21, 24, 43, 82, 92, 83, 114, 134, 145, 148, 150, 159 to 162, 164, 165, 167, 170, 173 to 175, 181 to 185, 188 to 190, 193, 198, 199, 203, 209 to 214, 217 to 220, 228 to 230, 253, 258 to 260, 262, 264 to 274, 278, 280, 282, 283, 294, 295, 298 to 300, 303 to 305, 307, 308, 318, 322, 328, 329, 331, 332, 335, 350, 351, 353, 357, 361, 362, 364, 372 to 374, 375). The illustrations of the following figures are from photographs kindly given by Mr. M. O. Parthasarathy Aiyangar, Professor of Botany, Presidency College, Madras, to whom I am also indebted for some suggestions. Figs. 32, 35, 64, 275 to 277, 288, 296, 297, 301, 302, 376-380, 382, 384 to 387. The photomicrographs of Figs. 106, 107, 151, 153, 155, 156, 157, 176,

287, are from slides prepared and kindly lent by Dr. M. A. Sampathkumaran, Professor of Botany, Central College, Bangalore. I am indebted to Mr. R. Debberman, Botanic Gardens, Calcutta, for Fig. 28 and to Mr. C. Tadulingam, Lecturing Botanist, Agricultural College, Coimbatore, for Figs. 235, 236 and 356. The Figs. 355, 360 and 368 are reproduced with the kind permission of Dr. F. H. Gravely, Superintendent, Government Museum, Madras, from the Collection of excellent drawings specially prepared for the Flora of Madras City.

April, 1925 }
Madras }

K. RANGACHARI

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SECTION I

MORPHOLOGY

CHAPTER I

INTRODUCTION

Living Things

Biology is the Science of life; that is, it is the study of living things, which are referred to as **Organisms.** The word **Biology** is derived from two words bios=life and logos=discourse or science. Round about us on the land, in the air, and in the water are thousands and thousands of different organisms, from the microscopically tiny plants to the gigantic trees like the Banyan or the *Eucalyptus* on the one hand, representative of plants, and from a tiny insect to the huge Elephant or Camel on the other hand, representative of animals. Biology is naturally divided into two branches : **Botany** (botane=herbs) which treats of plants and **Zoology** (zoo=animals) which treats of animals. Botany is a very important and interesting branch of science. Plants form the basis, as it were, of all life. All animals vegetarian as well as carnivorous, ultimately depend on plants for their food. The uses of plants for men are indeed very many. Every human being therefore, should possess a knowledge of at least the fundamental facts about plant life. The importance of botanical knowledge in the fields of Agriculture including Animal Husbandry, Forestry, Medicine, Industries, etc., is too well known to need any emphasis.

Living and Non-Living

The materials which surround us can be classified into two groups, namely, (1) **Living** (2) **Non-Living**. A living thing is one which is alive or in other words has the characteristics of life.

Life possesses certain characteristics that even now cannot be easily explained by men of science because they are so complex. However it is possible to define some characteristics whereby most living things differ from non-living things.

Characteristics of Living Organisms

1. **Life-Cycle.**—All living organisms, plant or animal, follow a definite cycle of birth, growth, reproduction, decay and death. A healthy well developed paddy grain when sown in good soil under normal conditions, starts growth with its embryo. The embryo becomes a seedling and then into a mature plant. When the vegetative growth ceases, the paddy plant flowers, produces

the grains and then dies. Again the life-cycle is repeated in the same fashion from seed so that the species is kept going and escapes extermination. This is the universal process with all plants and animals.

2. **Protoplasm.**—There is no life without protoplasm. Protoplasm is the jelly like substance which fills up all living cells in plants and animals. It is responsible for all vital functions. More details of protoplasm will be given while dealing with plant physiology. Suffice it to say here that it is the basic substance on which life is built, and that it is sensitive to stimuli like light, heat, chemical substances, electric shocks etc.,and that it manifests various kinds of movement; chemically it is a complex protein and very difficult of analysis as it is constantly subject to change

3. **Nutrition.**—A living organism requires food. Food plays the part of fuel for supplying the necessary energy for all life activities such as **movements, growth, repair** and **reproduction.** The chemical constituents of food are in fundamentals the same in plants as in animals. Without a regular supply of food there can never be any growth or development.

4. **Respiration.**—From birth to death every plant and animal respires. This is a very characteristic phenomenon of life in which organisms take in **Oxygen gas** from the atmosphere and give out **Carbon-dioxide gas.** On account of respiration, the energy stored up in food is released and made use of by the protoplasm for its numerous activities. If respiration is interfered with, life stops and there is death.

5. **Metabolism.**—This is a phenomenon of life which consists of two phases; namely, the constructive or **Anabolic** and destructive or **Katabolic.** In the anabolic process food is built up and protoplasm manufactured while in the katabolic, food is broken into simpler elements so that energy is released. Both these processes are essential for life.

6. **Growth.**—While dealing with life-cycle it was mentioned that from a paddy seed a paddy plant results. Similarly from a baby one can trace the different stages in the development of the human adult. All living objects, plants and animals, **grow.** Growth in living things is something quite different from the increase in size of certain non-living things such as the growth of stalagmites. A stalagmite is commonly produced by the evaporation of water from a solution of sodium bi-carbonate,and its growth is merely the result of the gradual addition of more bi-carbonate on the outer side of the crystal. But growth in plants and animals

is much more complicated as will be seen later on in the chapters in plant physiology.

7. Movements.—Movements are characteristic of life and more easily seen in animals than in plants. As plants are fixed to the ground their movements are restricted. Movements in plants and animals may be **spontaneous** or **induced**. These will be dealt with in greater detail later on.

8. Reproduction.—All living organisms plants and animals have the capacity to reproduce, i.e., the power to give rise to new individuals like themselves. There are laws governing reproduction which are coming to be understood more and more with the advance of knowledge in the special branch of science called **Genetics.**

Differences between Plants and Animals.—When one compares the lowest form of plants with the lowest of animals, i.e., unicellular forms, there is no appreciable difference except that in plant forms there is a green pigment. In the case of higher plants and higher animals the differences are more marked and they may be tabulated as follows :—

PLANTS.	ANIMALS.
(1) Most plants are stationary being fixed to the ground by roots.	(1) Most animals being free are capable of locomotion.
(2) (*a*) Growth is limited to certain regions like stem and root and other definite tissues in the interior.	(2) (*a*) In animals growth is not localised and all parts grow simultaneously.
(*b*) In plants growth continues from birth to death.	(*b*) Animals cease to grow long before death.
(3) Most plants are branched.	(3) Most animals are of a definite shape and are not branched.
(4) Except in the case of fungi, bacteria and total parasites, all plants have chlorophyll, or the green colouring matter.	(4) Animals have no chlorophyll.
(5) (*a*) Because of chlorophyll most plants manufacture their food from the raw materials (holophytic).	(5) (*a*) Most animals must have their food already manufactured (holozoic).
(*b*) Because of chlorophyll, plants have the power to decompose carbon-dioxide of the atmosphere and synthesise carbohydrates.	(*b*) Animals have no such power.
(6) (*a*) All plant cells have *cell walls.*	(6) (*a*) Animal cells have *no cell walls.*
(*b*) Mostly cell wall material is *Cellulose.*	(*b*) *Cellulose* is absent in animal body.

Sections of Botany.—We have to study plants from different stand points of view. For the sake of convenience these different views are considered separately each forming a section of Botany.

For example, we have to study the external features and the internal structure of the members or parts of plants. The former forms the section called **Morphology** and the latter constitutes **Histology.** The various life process have also to be considered and this forms the section of **Physiology.** The multitude of individual plants, we know, are varied in form and structure. We compare plants with one another and group them into classes or divisions. This part of Botany dealing with classification is called **Systematic Botany or Taxonomy.** It is also usual to deal with plant and speak about its relationship with its external surroundings or other plant communities. This is called **Plant Ecology.** Plants useful to man such as food crops, timbers, fibres, fruits, etc., are brought together under **Applied** or **Economic Botany.**

Plants are divided into four main divisions as shown below :—

1. **Thallophyta.**—This is the lowest division of plants and comprises the lowest and simplest of plant organisms. The plant body is either a single cell or an aggregation of similar cells without any differentiation. Though these, considered individually are small and inconspicuous, they are very numerous in species and genera. These include Algae, Fungi and Lichens.

2. **Bryophyta.**—These are the mosses and the liverworts. These plants do not show much differentiation into stem and leaf although in some higher forms some slight differentiation may be seen. In all situations where there is sufficient moisture mosses and liverworts flourish very well.

3. **Pteridophyta.**—Ferns, clubmosses, horsetails and selaginellas constitute this division. They resemble the spermatophytes in showing differentiation into root, stem and leaf in the plant body or cormus and also in internal structure. Propagation is not effected by **seeds,** but by special unicellular bodies called **spores.**

4. **Spermatophyta.**—They form the chief constituent of the flora of the land and are the highest type ofplant lifeat the present moment of evolution. These are highly organised plants with a very high degree of differentiation in their parts. Propagation takes place by means of seeds. The group is further divided into the two sub-divisions. **Gymnosperms** (Plants producing naked seeds) and **Angiosperms** (plants producing seeds enclosed in seed cases).

The first three groups together are often called **Cryptogams** and the fourth **Phanerogams** or flowering plants. Occasionally the term **Cormophyta** is used and it includes Pteridophytes and Spermatophytes.

CHAPTER II

THE PLANT

The plant body or the **cormus** of any plant consists of the parts, root, stem, leaf, flower, fruit and seed. From a close study of a few plants it becomes obvious that the cormus of all spermatophytes and pteridophytes consists of these primary parts, whatever may be the size and shape of the plant. These parts have definite functions to perform.

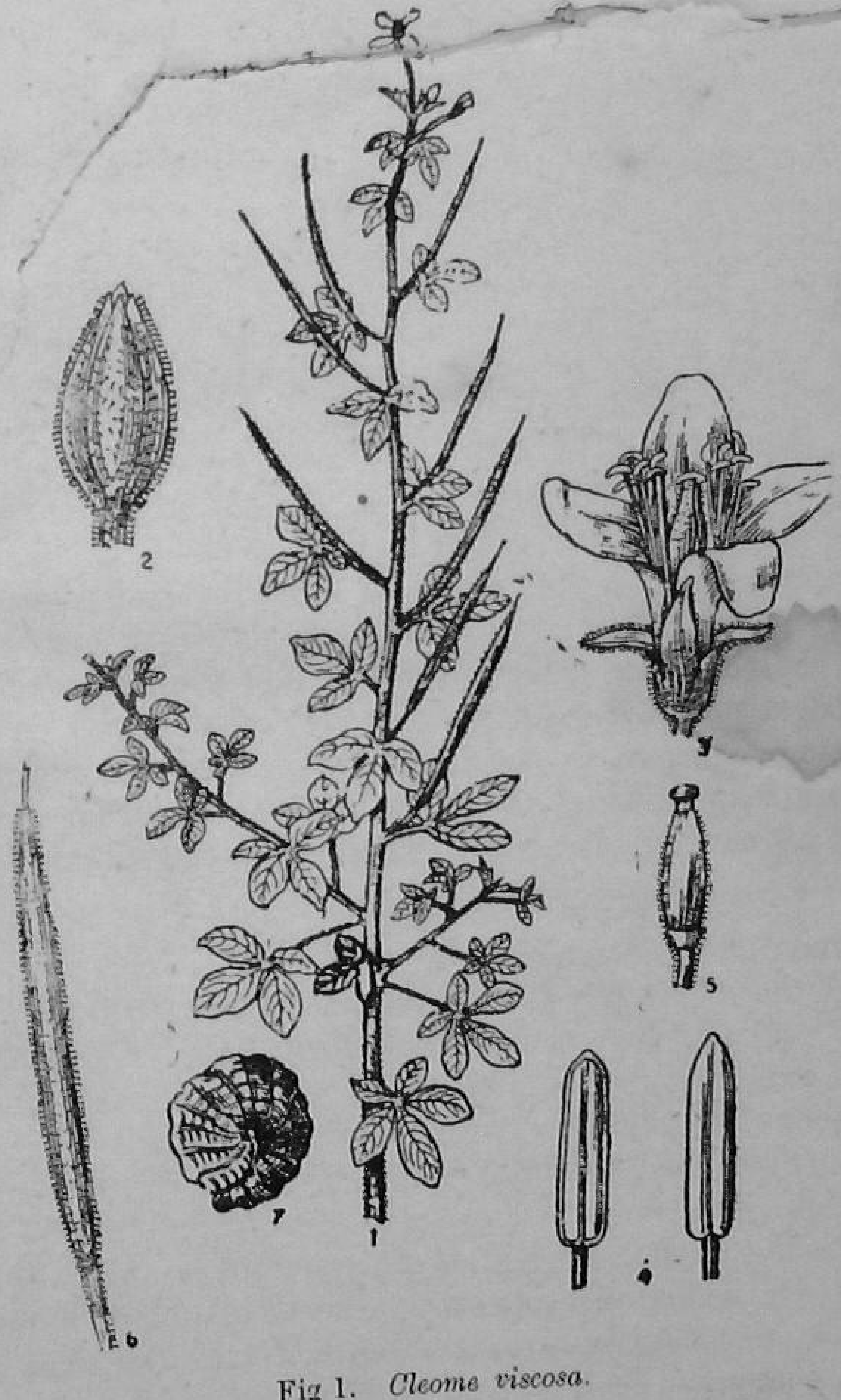


Fig 1. *Cleome viscosa.*

Example 1.—The plant *Cleome viscosa* growing in open wast places, will very well serve as a type. (fig. 1) As in every other flowe ing plant, in this plant also, the lower position of its body li buried in the soil. When we pull the plant from the ground we fir that we have to exert a little. From this we have to infer that tl underground part of the plant, called the **root system** helps in fixir the plant to the soil and prevents its being dragged out by the win If we dig out well grown plants with as little injury as possible the roots, we learn that the buried portion of the plant or its ro system consists of a **main** or **tap-root** going vertically downwar and several lateral or **secondary** roots. The root system of a pla is devoid of the green colour and all the parts are alike, only sor are thick and oth... On the other hand the aerial part hoot of the plant is green and consists of dissimilar parts.

The green aerial portion of this plant usually grows er and as a matter of fact, the tendency of the shoot is always grow upwards towards sunlight. The shoot consists of branch all more or less alike in structure. Each branch consists of a cent axis, the leaves and buds or small branches arising from it. T main stem which is in continuation with the tap root goes strai upwards whilst the branches grow obliquely. On the branch besides leaves and flowers, fruits also make appearance, alth leaves precede them in point of time. In the stem, leaves from definite points called **nodes,** and the part of the stem between any two successive nodes is named an **internode** internodes of a stem are not all of the same length but th gradually shorter and shorter towards the apex of the stem the leaves get crowded. At every node a bud arises fro angle or the **axil** formed by the leaf with the stem. Some o buds develop into branches and every branch repeats the char of the stem on which it arises. **In all flowering plants b: branches arise only from the leaf axils.**

The most conspicuous feature of a plant is the presen leaves and the whole mass of leaves of a plant is known as **foliage.** As a rule, the leaves are first formed and later on flowe and fruits are developed. In the plant *Cleome viscosa* leaves a borne singly at every node. The mode of arrangement of the leav on the stem is termed **phyllotaxy.** Each leaf has a leaf stalk **petiole** which bears three to five small green pieces called **leafle** all separate and as such one leaflet may be removed without inju to others. In the leaf of this plant we see a long petiole having **blade** which is cut up into distinct leaflets and this type of le is called a **compound leaf.** The leaflets do not bear buds in th

axils and this is one of the distinguishing features between a leaf and leaflet.

The leaves are so arranged all round the stem as to enable most of the leaves to be exposed to sunlight. In this plant, the lower leaves have longer petioles and the length of the petiole gradually decreases towards the stem apex. There are many other contrivances in other plants to expose the leaves in an efficient manner to sunlight.

In the axils of leaves of this plant, bright yellow flowers are borne. Each flower has its own stalk, called the **pedicel** and its free end bearing the floral parts is termed the **receptacle, thalamus** or **torus.**

On examining a flower bud or an open flower, we see on the outer most side [illegible] e bud, four narrow green structures and these are **sepals** and [illegible] whorl of sepals is known as **calyx**. The most conspicuou[illegible] ring of yellow leaves seen in the flower, next inner to the sepals is the **corolla** and the members of this whorl are **petals.** About ten to twenty five thread like structures with small sac-like bodies at their tips arise from about the base of a flask shaped body (**pistil**) and are disposed [illegible]ound it. These are the [illegible]mens or the **andrœ-**[illegible] (male apparatus). [illegible] sac-like bodies at [illegible]nds of these threads [illegible]called **anthers** and [illegible]n the anther we [illegible] the yellow dust [illegible]ed **pollen** or **pollen** [illegible]**ns.** In the centre of [illegible]flower is a very young [illegible]ucture which later on [illegible]velops into fruit. This [illegible] termed the **pistil** or the **gynœcium** (female apparatus). In consists of three parts: the cylindrical dilated portion or the **ovary,** the short column or **style** connecting the ovary to the knob at the top, the **stigma**.

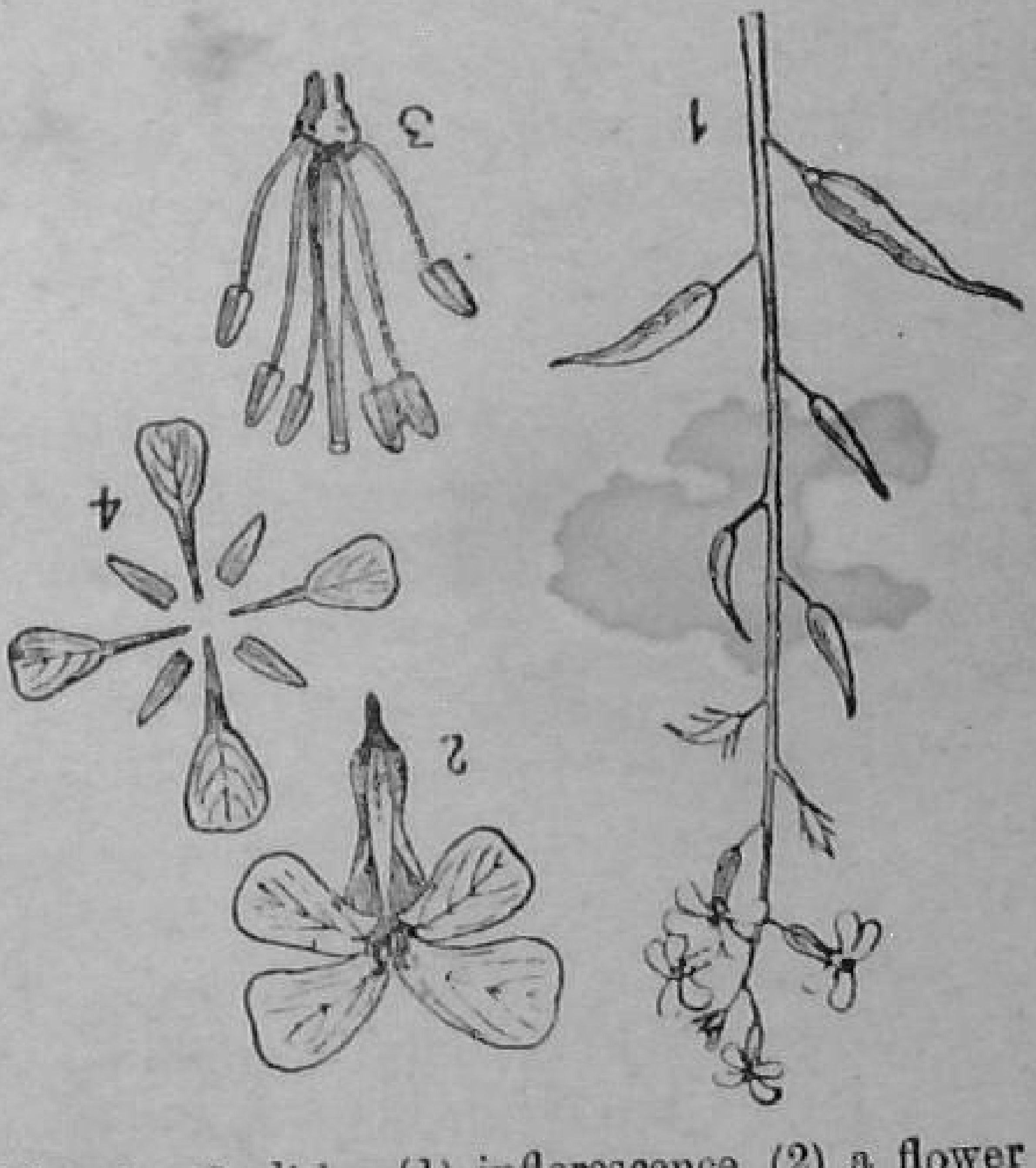


Fig. 2. Radish. (1) inflorescence (2) a flower (3) Stamens and pistil (4) Sepals and petals.

In flowers, at the time of their opening and when they are fully opened all the four parts above described *viz.*, calyx, corolla, androecium and gynoecium, are present; but if we examine them

later at different times, we do not find all the parts. In some we may find all the parts but the sepals and petals may be in a faded condition and about to fall off. In others they may have fallen, leaving only faded stamens. Pistil instead of remaining small, grows and therefore, its size varies according to the stage of development. From this it is clear that certain parts only are directly concerned in the production of seeds and these must be considered as most necessary and hence the **essential** parts of the flower. The pistil is undoubtedly one of the essential organs, because it contains the young seeds. As no seeds can be formed without the help of the stamens they also constitute the essential part. The pollen grains formed in the anthers of the stamens seem to influence in some way the formation of the seeds. For this, the pollen grains must be deposited on the stigma and this transference of the pollen grains from the anthers to the stigma is termed **pollination.** Subsequent to this, **fertilisation** is effected. The sepals and petals are only the enveloping parts affording protection to the two inner organs, the stamens and pistil until they are mature and ready to do their functions and these are the **accessory** parts of a flower.

After fertilisation, the pistil develops into the fruit. The **fruit** of *Cleome viscosa* is simple in its structure. It is cylindrical consisting of a wall or **pericarp** enclosing a single cavity. The seeds are attached to the pericarp in three or four lines. The seeds of *Cleome viscosa* are dark in colour, discoid and irregularly furrowed all over.

Example 2.—As our next example we may select *Tribulus terrestris*, which is generally met with in waste places. The whole plant is softly hairy with all the branches of the shoot system lying prostrate on the ground; its root system does not differ materially from that of *Cleome viscosa*, but the tap root is longer.

The branches growing in all directions in a prostrate radiating manner bear leaves in abundance and at every node; here are two leaves, one opposite the other. Generally one of these at the node is smaller than the other and occasionally it may also be absent. At every node four triangular green pieces occur close to the base of the leaves as outgrowths and these are the **stipules**. The petiole is generally short and the blade consists of several small leaflets disposed on both the sides of the midrib of the leaf. So this is also a compound leaf as in *Cleome* but of another type.

Flowers arise singly from the axils of leaves and every flower has the same four parts found in the flower of *Cleome viscosa*. In the *Tribulus* flower there are five green sepals, soft and hairy outside forming the outermost whorl of the flower. Between and

higher above the sepals, we find five yellow wedge shaped petals. We find inner to the petals, first, a whorl of five short stamens alternating with them and another whorl of five longer stamens a little higher up alternating with the first whorl of short stamens. In the centre of the flower lies the pistil with the ovary and stigma well marked although the style is almost absent. The ovary has five cavities and in each cavity lies a row of ovules. Thus, we see that sepals, petals and stamens alternate with one another successively and are placed in whorls.

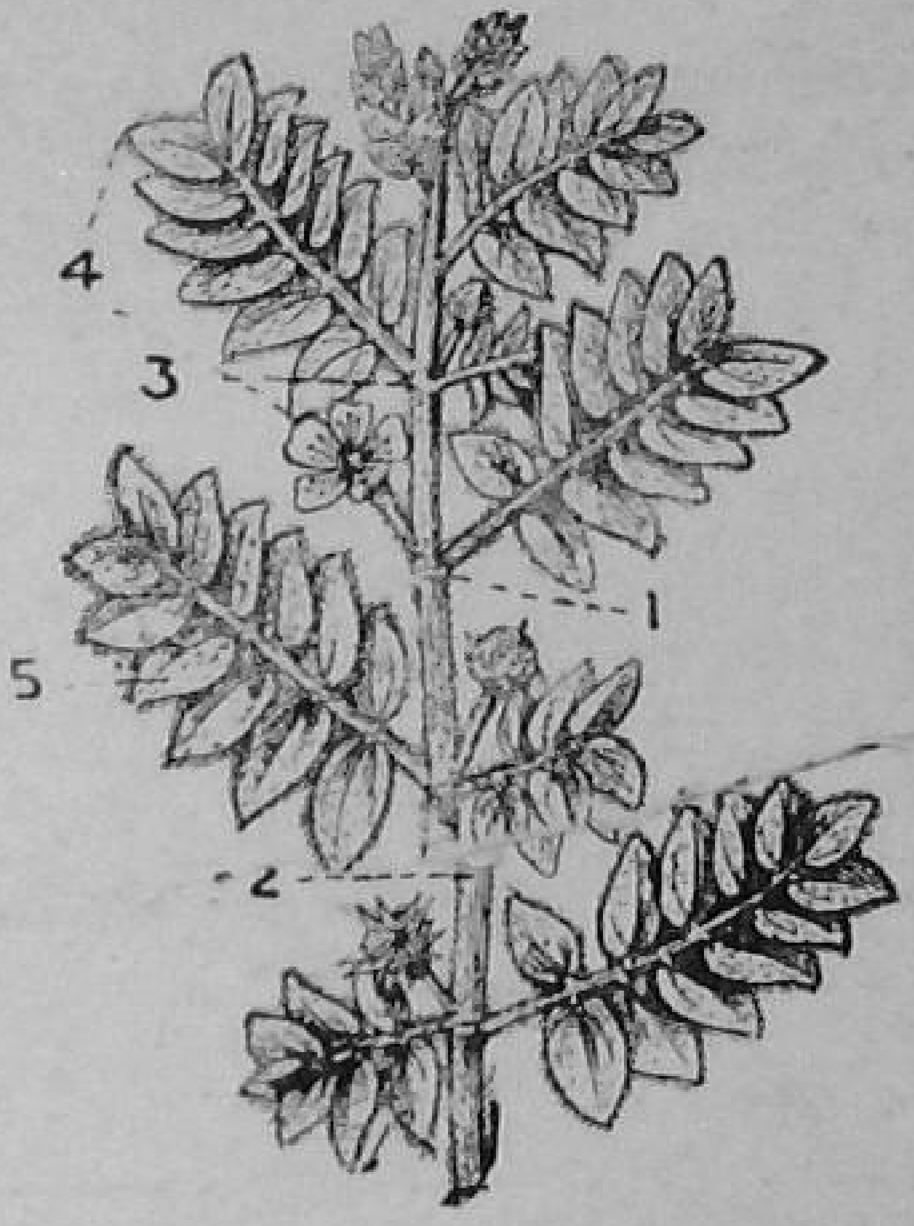


Fig. 3. *Tribulus terrestris* (1) node (2) internode (3) Stipule (4) leaf (5) leaflet.

The fruit of *Tribulus terrestris* is rather interesting in some respects. Each of the five lobes of this fruit bears at its back two pairs of spines, the upper pair being longer than the lower pair. The fruit breaks up into five segments when it is fully ripe. Inside each of these five segments of the fruit there are four to six thin flat ovate seeds. The hard covering and the spines help in not only affording protection to the seeds but also considerably in their dispersal.

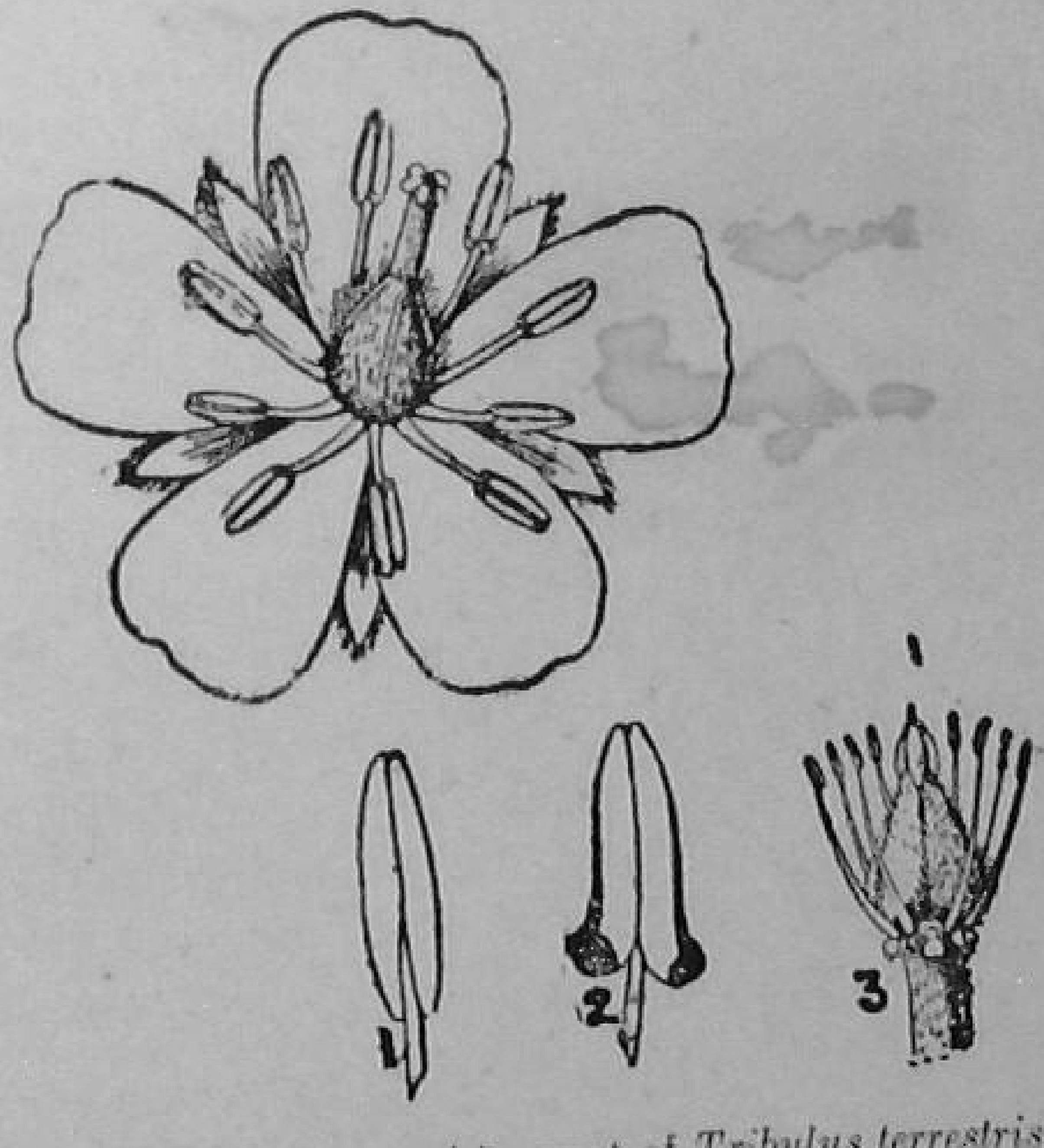


Fig. 4. Flower and its part of *Tribulus terrestris*, (above) full flower, (1) and (2) Stamens (3) stamens and pistil.

From the above study, we learn that plants have definite parts and that those parts are more or less, similar in essential points in all plants. In every green plant, whatever its size, there are two distinct parts, namely, the **root-system** and the **shoot-system.** The root system is usually uniform

in character. It generally consists of a ta[illegible] bearing several lateral roots. Of course, they differ in [illegible] according to the development of the plant as a whole. The shoot system possesses uniformity only with respect to the position and formation of branches but considerable differences are seen in other respects. The flowers show the largest amount of variation in all their parts.

Fig. 5. Fruit of *Tribulus terrestris* and its segments (1) fruit (2) fruit cut accoss (3) side view of fruit (4) one segment.

Both the root system and shoot system are mainly concerned in the work of **nutrition** of plants, whilst flowers are concerned with the process of **reproduction** or **sexual propagation.**

[illegible]d of plants.—Every plant has a definite course of its life. A plant begins its life as an embryo enclosed in a seed in a dormant state, then it germinates and grows into a seedling, grows, puts forth the leaves and branches, sends its roots into the soil where they branch and spread, ramifying the soil in all directions. Later on, flowers appear and they remain attractive and fresh for a while and after doing their work they fade away. The stalk or the pedicel which bore the flower, now supports the developing fruit, within which seeds ripen, and when the fruits are mature the seeds are liberated; these are really so many young plants let loose to travel as best as they can and thrive as distinct individuals. All these events in the life of a flowering plant, occurring in regular sequence, constitutes its life history.

The life period of a plant, or its generation may be short or long. If the generation lasts only one season, the plant is called an **annual** ; if for two seasons it is a **biennial** ; when it lasts for three or more years the plant is a **perennial.** There are some plants, like some species of bamboo that live for many years but flower only once and die soon after the seeds have fallen. These are called **multie[illegible]ials.**

CHAPTER III

STRUCTURE AND GERMINATION OF SEEDS

Seed is an embryonic state of plant resulting by the development of ovule subsequent to fusion of gametes or **fertilisation.** Many plants spread from place to place by dispersing their seeds far and wide. These latter germinate and give rise to seedlings. A typical seed consists of an **embryo** with stored food protected by **seed coats.** The stored food may be in the embryo itself as in the bean seed, or it may be outside the embryo as in the castor seed. The embryo is really a tiny plant. It consists of an axis the lower end of which develops into root and the upper end into shoot. It has also seed-leaves, one (in monocotyledons) or two (in dicotyledons). When external conditions are favourable, the embryo begins to increase in size by growth and develops by stages into a mature plant.

The **embryo** or the young plant is the essential part in all seeds, and this part is always protected by one or two firm seed-coats. The seeds of plants have to sojourn in the ground, and so they may very often be subjected to extremes of temperature or other unfavourable conditions. Unless the embryo is well protected from the evil effects of these conditions, it may perish. The seed-coat forms an efficient means to ward off the evil effects.

Every flowering plant makes supreme effort to propagate its kind by producing as many little plants or embryos as possible, packed compactly in seed-coats. Inasmuch as these little plants within the seeds get separated from the parent plant, each seed is really a separate individual. Mere production of seeds and their separation from the parent plant counts for nothing, unless they are equipped with the means to withstand unfavourable conditions. Seeds in unripe fruits contain large quantities of moisture and as they mature they gradually lose the moisture, and finally when they are fully mature and about to be detached from the parent plant, they become very dry. Dry seeds are better able to withstand the bad conditions and ward off the evil effects than living plants which contain much water. In a dry state, seeds are capable of passing through a long resting stage.

In nature, seeds are scattered at a time, when the conditions are not always very favourable for their germination or start in life. The dormant stage of seeds is not without its use. During

this period chemical and other changes, such as the loss of water already started and going on in mature seeds, are now completed. Unless these changes are completed, the young embryo within the seed runs the risk of being roused into activity, which, however, cannot be continued long on account of the want of favourable conditions, and consequently it perishes. The drying process, besides equipping the embryo with power to resist unfavourable conditions, renders the food-material stored in the seed stable. Hence it is a common practice to dry all our food stuffs which are in the form of seeds, as for example, red gram and black gram, paddy, etc.

Not all seeds are alike: a bean seed looks different from castor seed and a castor seed from rice seed or coconut. They are different not only in their external morphology but also in their internal structure. In order to understand the growth and development of the plant from the seed, it is necessary to know the structure of the seed. A few typical seeds are described below.

3. **Bean Seed.**—(Dicotyledonous ex-endospermous seed). We may begin the study of the structure of seeds with those of *Dolichos Lablab.* (Fig 6). The seeds are attached in the fruit to the ventral suture by means of short stalks. When they mature and dry, they get detached from the fruit. So in every seed a scar is seen on one of the edges, at the end of the spongy white streak found on the seed. This scar is called the **hilum**. At the other end of the white streak, away from the hilum, a minute hole exists in the seed-coat. The presence of this hole, or the **micropyle** as it is termed, (**mikro**, small; **pyle**, a gate) can be inferred from the fact that water comes out of the hole when a soaked seed is pressed between the fingers.

A seed is essentially an embryo or an young plant resulting from sexual reproduction and enclosed in a casing. In a soaked seed, if the seed-coat is slipped off, the embryo comes into view. The **embryo** consists of a curved axis called the **primary axis** and two large flattened seed-leaves or **cotyledons,** which are attached to this axis, dividing it into an upper part or the **plumule** and the lower part or the **radicle.** The plumule lies compressed between the seed-leaves and this is the part that later on develops into the shoot-system of the plant. The radicle, or the lower portion of the primary axis, which later on gives rise to the whole of the root system of the plant lies usually outside the cotyledons and on one side of them. The seed-coat within which the embryo lies free, without being attached to it in any place, is somewhat

thick, and, as a matter of fact, it consists of two coats, an outer thick coat, the **testa** and an inner thinner one, the **tegmen.**

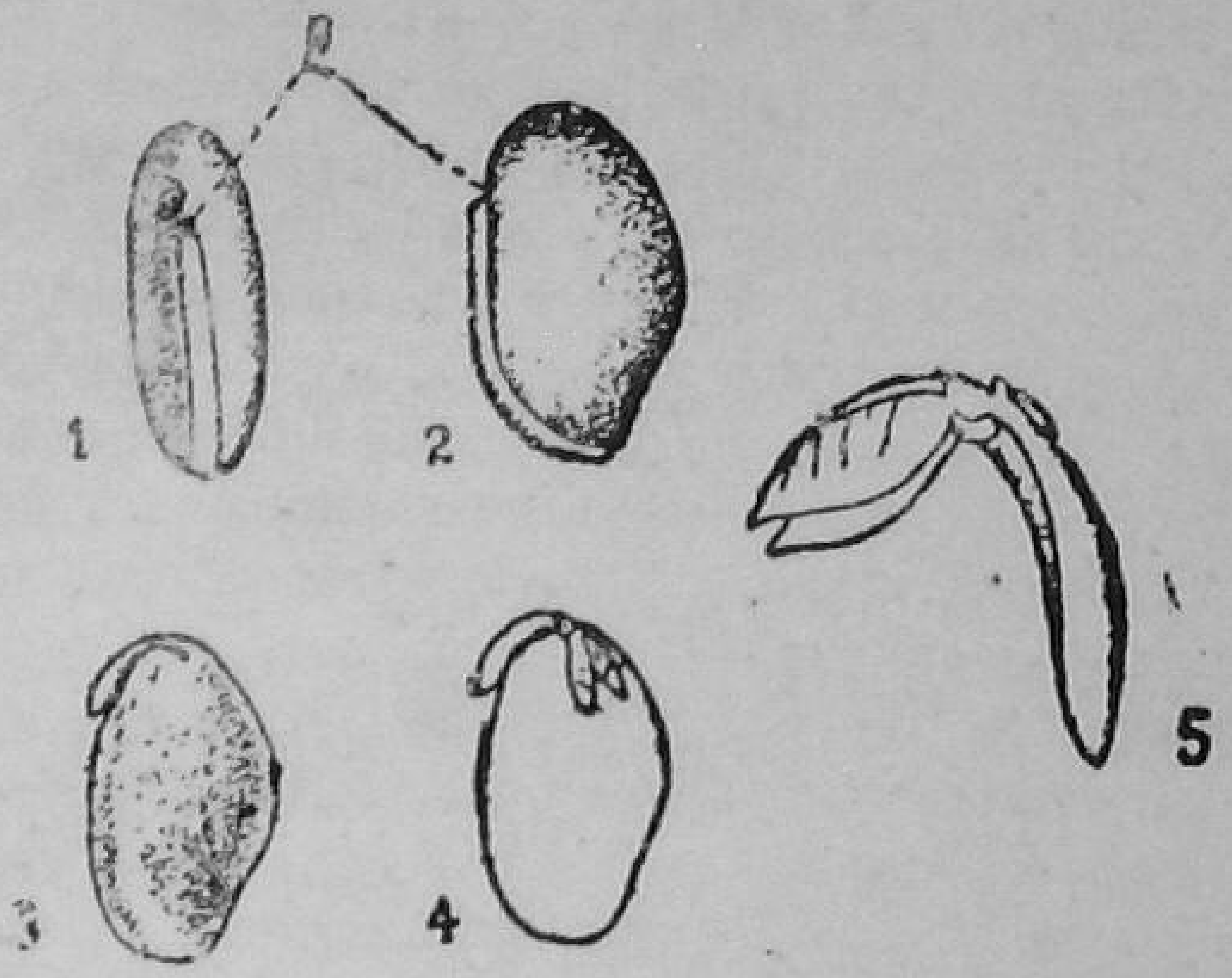


Fig. 6. *Dolichos Lablab* seed and its parts. (1) and (2) seed. (3) embryo. (4) embryo with one cotyledon removed and showing the embryo. (5) primary axis.

The parts thus recognised in the seeds of *Dolichos Lablab* are present in a large majority of seeds of dicotyledons, which take their name from the paired seed leaves. But the seeds may vary very much not only in their shape and size, but also in their parts. All this can be made out by examining a few more seeds, such as those of Mango, *Cucurbita and Raphanus.*

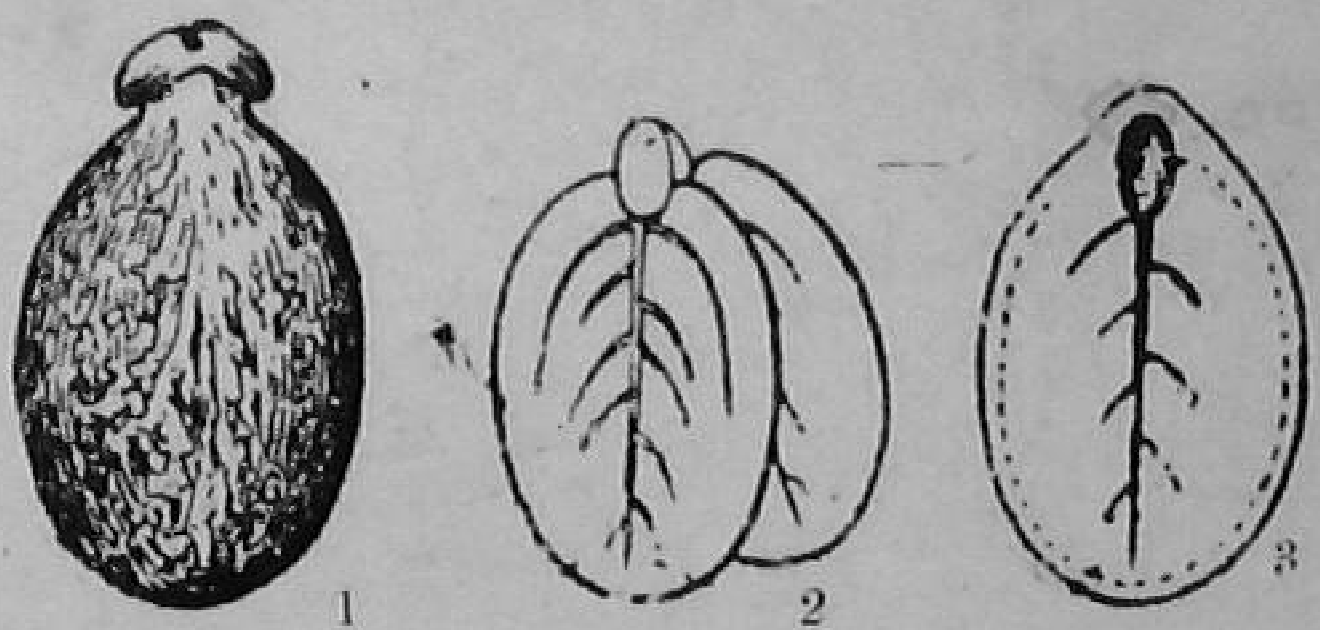


Fig 7. Castor seed and its parts. (1) full seed. (2) embryo. (3) endosperm.

Castor seed.—(Dicotyledonous endospermic seed). As our second example we may select the castor seed. (Fig. 7). This is also a dicotyledonous seed having the embryo within the seed-coat just like the *Dolichos Lablab* seed, but differing from it in one important respect. A special additional tissue called **endosperm** is found within the castor seed, and this is not present in the

Dolichos seed. Endosperm contains reserve food material which is utilised by the embryo when the seed germinates.

The castor seed is a large one with a brown, hard, brittle polished **testa** mottled all over, with streaks and blotches. Within this **testa** lies the massive endosperm wrapped up by the **tegmen.** If this mass of oily endosperm is split down in the middle in the plane in which the seed is flattened, the embryo is seen consisting of a short peg like primary axis, with which are connected two thin papery cotyledons. On a close examination it will be found that the cotyledons are immersed in the endosperm, in such a way that practically the whole of the outer surfaces of the seed-leaves are in intimate contact with it. Seeds, such as those of *Ricinus communis* (castor), in which the tissue endosperm is present, are called **endospermic** or **albuminous** seeds. By contrast, seeds, such as those of *Dolichos* and the like in which the endosperm does not occur, are called **non-endospermous** or **ex-albuminous** seeds.

Date palm and Crinum seeds (Monocotyledonous endospermous seed).—We have next to consider the structure of the seeds with one cotyledon only, that is to say, of monocotyledonous plants. As examples of this class of plants, the seeds of Date-palm and *Crinum* and the grains of Maize or other cereal plants may be examined.

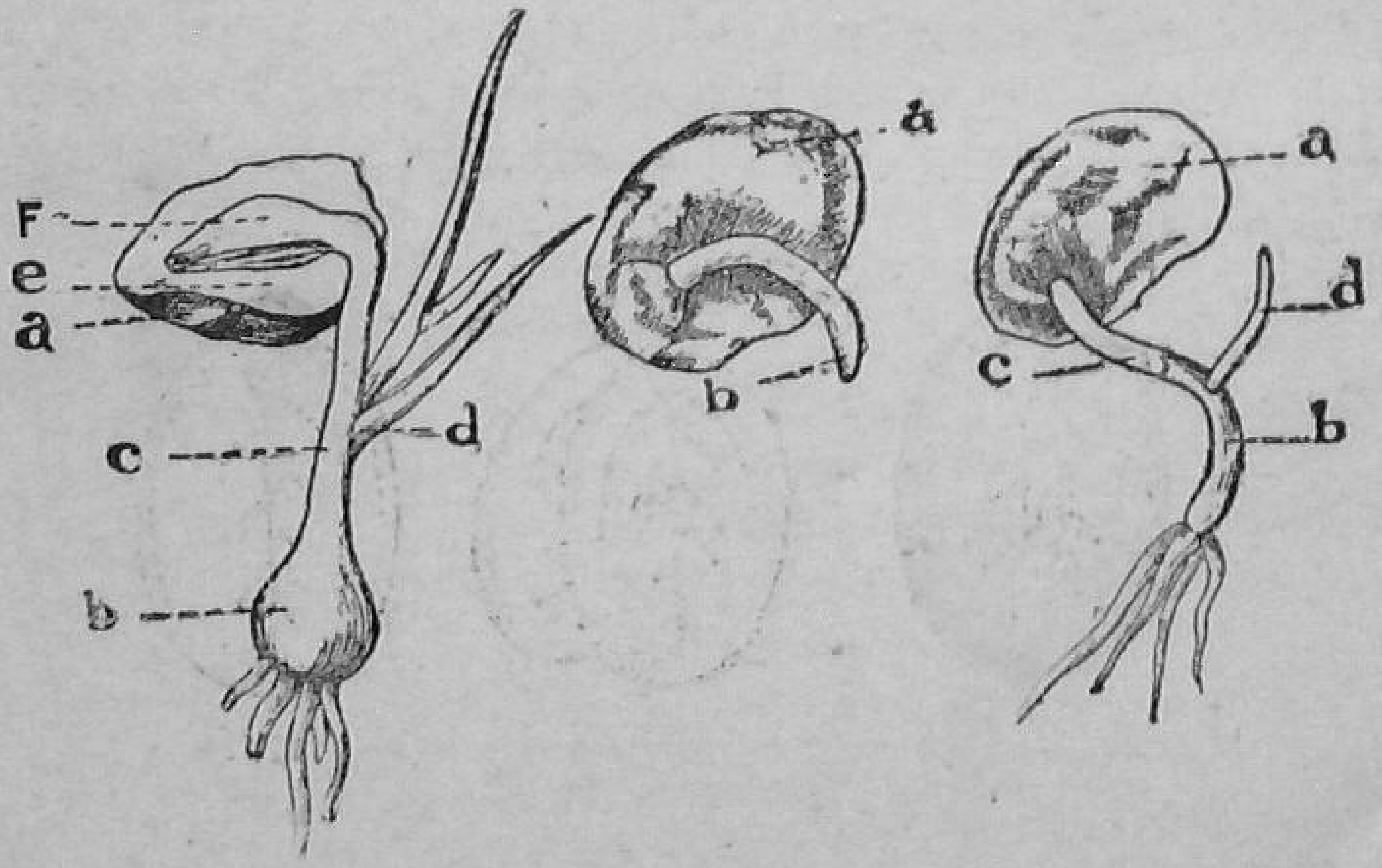


Fig. 8. *Crinum* seed, (*a*) endosperm. (*b*) hypocotyl. (*c*) stalk of cotyledon (*d*) plumule (*e*) endosperm cut through (*f*) cotyledon.

The Date-palm seed is very hard and, therefore, it is often called " date stone." It is somewhat cylindrical and pointed at both ends (Fig. 12). On one side of it, about the middle, a small

pit is present. This shows the position of the embryo. A very shallow groove runs from this pit towards one end and on the other side of the seed there is a deep furrow extending from one end to the other. If the date seed is cut through the pit both transversely and longitudinally, the tiny embryo will be seen lying in the hard horny endosperm. The thin brown outer layer covering the stone is the seed coat. The *Crinum* seed (Fig. 8), though similar to the date seed in essential respects, is larger, irregular in shape, and the endosperm is not hard. The embryo is small as in the date seed.

Maize Grain (Monocotyledonous endospermous seed).—The Maize grain is broad and rounded at one end whilst the other end, the point of attachment to the spike, is somewhat tapering. The two faces are flattened and on one face we see an oval depression due to the presence of the embryo. At the broad end, on the top of the face wherein lies the embryo, a small scar may be seen. This is the place of attachment of the stigma. The presence of these two scars, one at the narrow end and the other at the broad end, clearly indicates that **the grain is really a fruit enclosing a single seed.** In the Maize and, as a matter of fact, in the grains of all grasses, the so-called seeds are really fruits. In all these grains the **seed-coat fuses with the pericarp,** so that the two cannot be distinguished from one another.

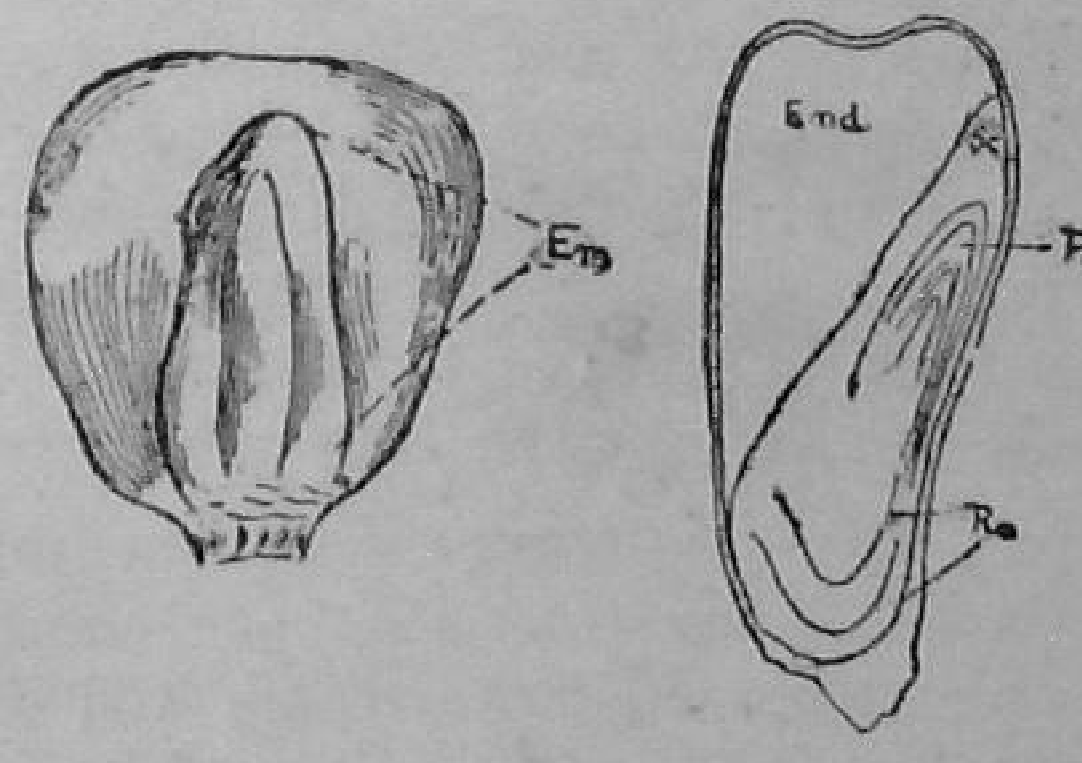


Fig. 9. The maize grain and its longitudinal Section. *Em*-Embryo. *End*-Endosperm; *Sc*-Scutellum; *Pl*-Plumule; *Ra*-Radicle.

To get an insight into the parts of the maize grain, a soaked grain should be dissected and observed. (Fig. 9). In such a grain the outer skin may be removed easily and then the embryo is exposed on the side in which a depression is noticed. By careful manipulation the embryo can be detached from the grain, and then it will be seen to consist of a straight axis with the shieldlike single cotyledon, called the **scutellum** attached to about its middle. The bulky part left in the grain, after the removal of the embryo is the endosperm. The primary axis consists of the plumule and the radicle. There is a protective cone like sheath for the plumule called the **coleoptyle** and one for the radicle called the **coleorhiza.**

The position of the axis and the scutellum can be clearly made out in the transverse and longitudinal sections of the grain. The cotyledon folds over the primary axis and its outer surface lies in close contact with the endosperm and this **Epithelial layer** acts as an absorbing organ or a **Sucker.**

The plumule develops into the shoot system of the plant. It also increases in size by growth, emerges out of the enclosing seed coat which is already split open by the radicle. In regard to the emergence of the plumule, seeds are broadly classified into two groups: (1) the upper end of radicle lying just below cotyledons called hypocotyl elongates rapidly and pushes the cotyledons and the plumule upwards out of the soil surface ; the seed is then said to have **epigeal germination** and (2) the lower end of plúmule lying just above the cotyledons called **epicotyl** elongates rapidly and the plumule alone is pushed upwards out of the soil surface leaving the cotyledons buried in the soil ; in this case the seed is said to have **hypogeal germination.**

The germination of a few types of seeds is briefly described below.

1. Germination of bean seed (Epigeal).—Whilst the roots are gradually developing from the lower end of the radicle, its upper portion lying below the cotyledons, the **hypocotyl,** is slowly growing and increasing in length. As the roots are fixed well in the soil, this elongation of the hypocotyl has the effect of pulling out from the seed-coat and lifting cotyledons up into the air. The hypocotyl comes out from the soil in the form of a loop, and the loop is the more mature region of the hypocotyl which pushes its way through the ground dragging after it the cotyledons, between which lies the plumule. The curvature straightens out, as soon as the cotyledons come out of the earth.

The early stages of germination take place within the soil in darkness, and therefore, the embryo cannot be expected to be able to manufacture starch and other food materials then. So, for the growth of the young plant, food materials must be provided for. As a matter of fact, in *Dolichos Lablab* seedling whose germination we have been describing, the early growth of the embryo takes place at the expense of reserve food material stored up in its thick cotyledons. The gradual removal of the food material from the cotyledons can be easily inferred from an observation of the seedlings at successive stages of development. In young seedlings the cotyledons are usually well filled and plumpy, in older ones, they are shrunken in appearance and eventually they become thin and disappear.

2. Germination of pumpkin seed (Epigeal).—The germination of pumpkin seeds (Fig. 10) presents certain interesting features, although it does not differ very much from that of *Dolichos Lablab* seeds. As in other seeds, the radicle comes out through the narrow end and develops into the root and later on, lateral roots arise from it in the usual manner. At the time of the escape of the radicle the slit is very small, but as soon as the root-system is well developed the hypocotyl and the cotyledons grow and exert pressure on the seed-coat, which is helpful in widening the slit. Further to facilitate the pushing up of the upper half of the seed-coat the lower half is pinned down firmly to the ground by the formation of a peg-like swelling at the base of hypocotyl. (Fig. 10). This swelling or peg keeps down the lower half of the testa and the cotyledons which are growing inside, press on the upper part of the testa. Thus the opening becomes wider and the cotyledons come out of the seed-coat easily. The cotyledons, though thick and small in the seed, grow larger after escaping from the seed-coat and behave like leaves.

3. Germination of castor seed (Epigeal).—The castor seed being an endospermic seed, its behaviour during germination differs from the seeds already described. The formation of the roots and the liberation of the embryo take place exactly as in the seeds of *Dolichos Lablab*. As there is a large quantity of endosperm, the cotyledons grow larger, absorb the reserve material and transmit it to the growing seedling. Until the endosperm is exhausted, the cotyledons do not come out and when it is almost fully used up they come out, become green and behave just like leaves. The endosperm consists of oil and protein grains and the cotyledons which come out into the air are

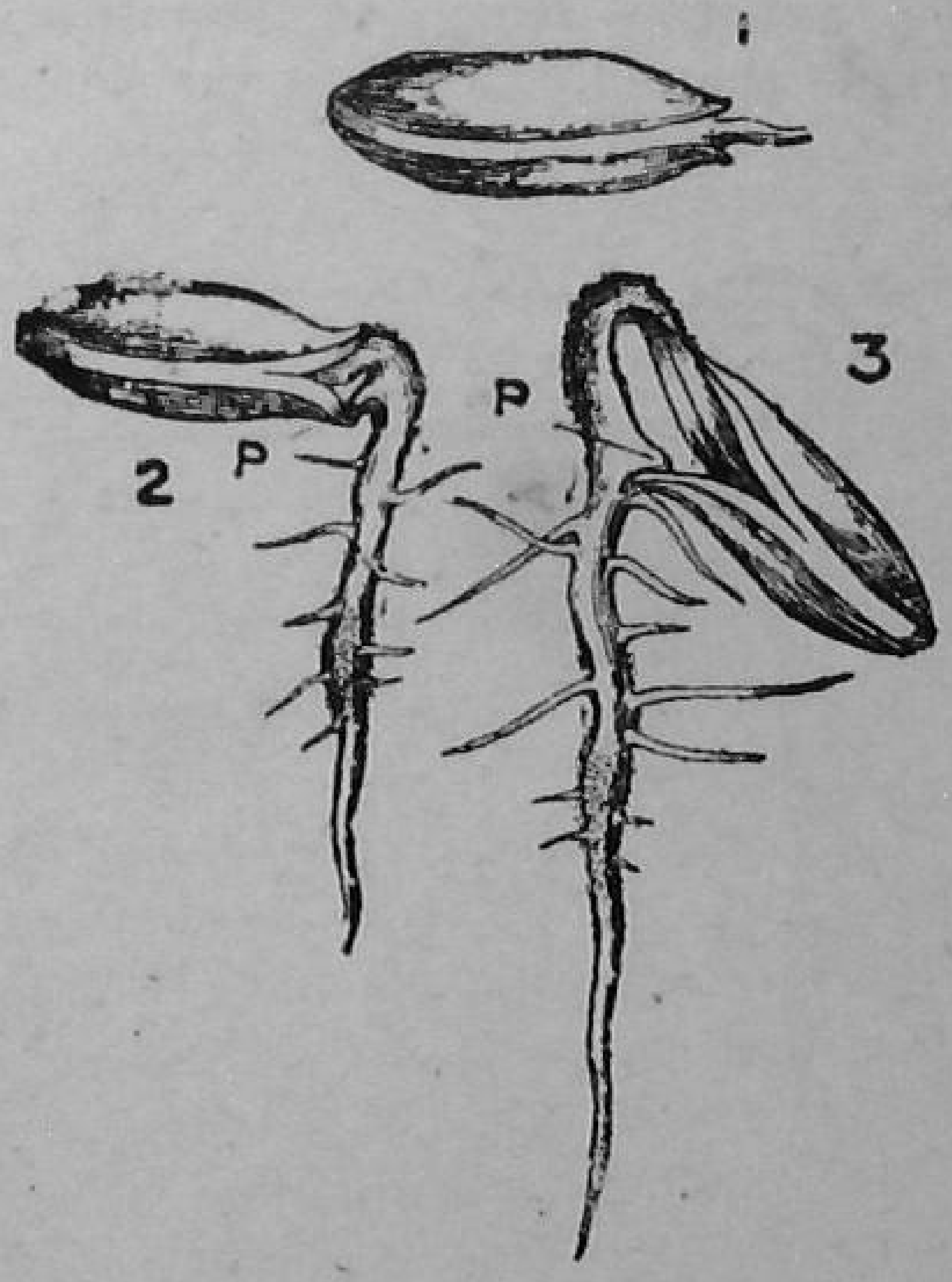


Fig. 10. Germinating *Cucurbita* seeds. (1) Seed just germinating (2) and (3) seeds with advanced germination; *P*-peg- like structure holding the lower portion of seed coat firmly.

covered by the thin layer of endosperm. The cotyledons absorb the oil which is now changed into a soluble sugar and the proteins from the endosperm until they are fully exhausted. The endosperm disappears in about ten to fifteen days' time. After the exhaustion of the endosperm the cotyledons which are now fairly well grown expand and behave like leaves, although these differ from the foliage leaves in form. The cotyledons are oval and their margins are entire, while the foliage leaves have deep lobes and many rib-like veins.

4. Germination of Cicer and Mango seeds (Hypogeal).—The behaviour of the radicle, so far as the formation of the roots are concerned, is exactly the same as in all other dicotyledonous seeds. But we notice differences in the manner of the escape of the plumule from the seed. In the case of *Dolichos* seeds, whose germination we have considered, all the parts above the upper portion of the radicle or the hypocotyl are lifted up into the air, by the active growth and elongation of the hypocotyl. But there are seeds, such as those of Mango, *Cicer* (Fig. 11) and Pea, in which, whilst the radicle is growing during germination, the stalks of the cotyledons and the lower portion of the plumule which is just above the cotyledons, called the **epicotyl** begins to grow. The cotyledons remain in the seed-coat and the roots are firmly fixed in the soil. Therefore, the elongation of the epicotyl results in pulling out the plumule clear off the seed-coat. During the time the epicotyl is growing, the greater portion of the plumule and its tip undergo but little alteration in size. The tip of the plumule, remains in a curved condition and it is really the mature portion of the epicotyl that pushes its way through the ground. As soon as the plumule comes up to light above the ground, it straightens itself and leaves formed in the plumule while it is underground, are very small and scale-like.

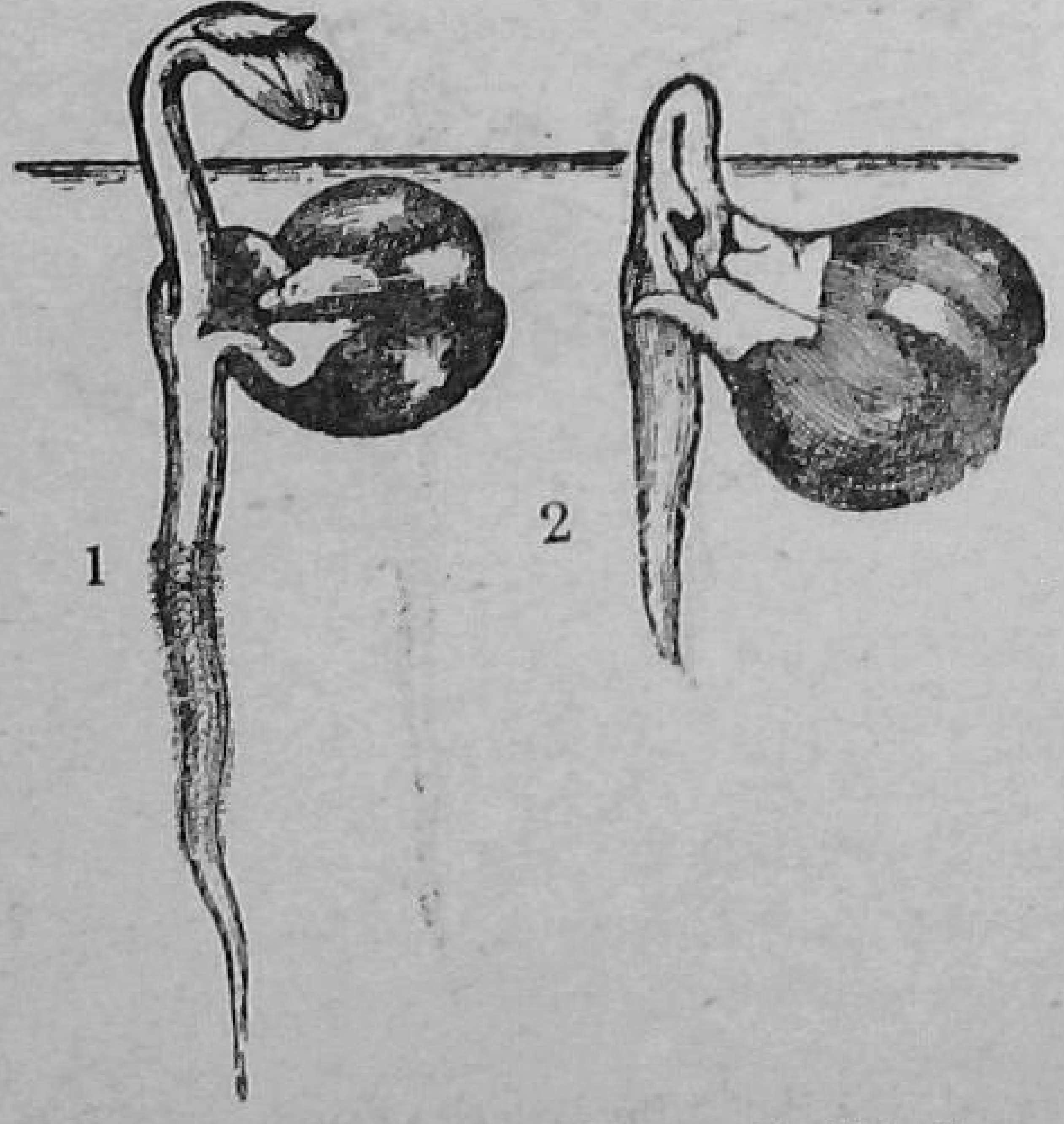


Fig. 11. Germinating *Cicer* seeds. (1) advanced seedling. (2) young seedling.

5. Germination of date and palmyra palm seeds (Hypogeal).—The germination of Date seed is very striking in certain respects (Fig. 12). The tiny embryo, lodged in the small pit at about the middle of the date stone, begins its activity as soon as water is absorbed. The stalk of the cotyledon sheathing the primary axis grows and consequently the primary axis is pushed out rapidly. At the lower end of the primary axis, roots arise and from the slit in the upper portion comes out a stiff pointed structure, the plumule which is made up of young leaves one folded within the other. For the growth of these parts food material has to be supplied and it must be obtained from the endosperm. The cotyledon which lies embedded in the endosperm grows gradually larger and larger, as germination progresses

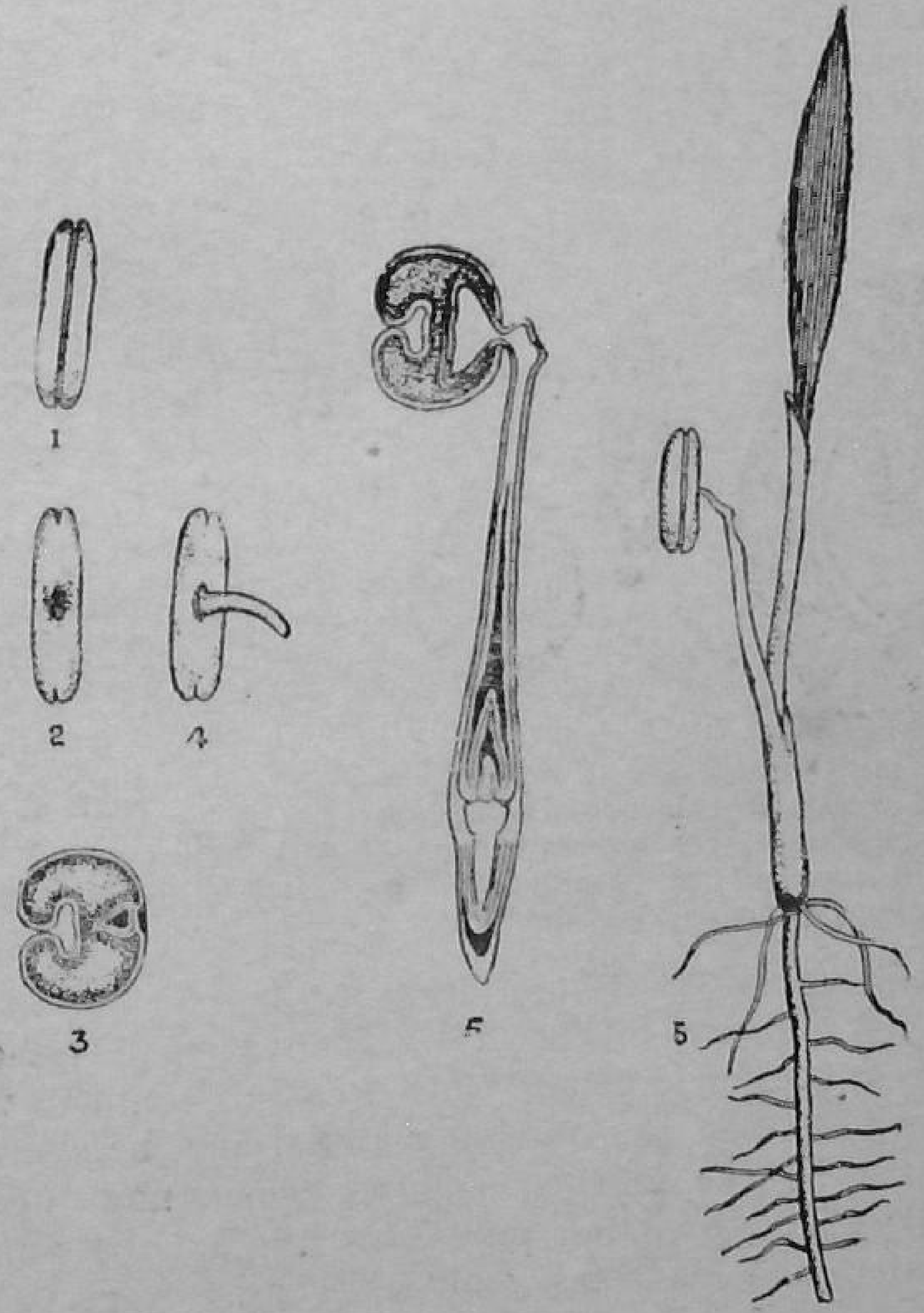


Fig. 12. Germinating date seed (1) Seed on the groove-side. (2) Seed on the embryo-side. (3) Cross-section of the seed at the embryo. (4) Seed just germinating (5) & (6) Early and late stages of germination.

and its surface also increases. Simultaneously with this the endosperm gets softer and softer and the cotyledon, now having a large surface, absorbs the food material almost like a 'sucker' and transmits it to the seedling through its stalk.

The cotyledon, though very small in the embryo in the resting stage, increases considerably in size during the germination of the seed both in *Crinum* and date.

6. Germination of Crinum Seeds : (Hypogeal).—The germination of *Crinum* seeds is practically similar to that of Date stone (Fig. 8). The endosperm is not hard and the cotyledon is different in shape.

7. Germination of Coconut (Hypogeal).—A notable example of the cotyledon assuming a very large size is afforded by the coconut. The embryo in the nut is very small and it lies embedded in the white fatty endosperm, just below one of the three openings of the shell at one end. For germination the coconut is buried in the soil with its husk intact. If the husk is removed germination is not possible. During the earlier period of germination a portion of the cotyledon grows out through one of the openings in the shell and carries the whole of the primary axis out with it. The greater portion of the cotyledon lies within the seed inside the shell and it absorbs the endosperm, as in Date and becomes larger and finally fills the cavity completely (Fig. 13). The external surface of the enlarged cotyledon comes into close contact with the endosperm so that the reserve material may be absorbed and transmitted to the growing embryo, which now lies outside the shell. As germination progresses, the axis becomes stouter and stouter and elongates, and roots arise from it one after another and grow downwards into the husk and finally pierce the husk and reach the soil. The upper portion of the axis, or the plumule, grows and goes upward piercing through the husk.

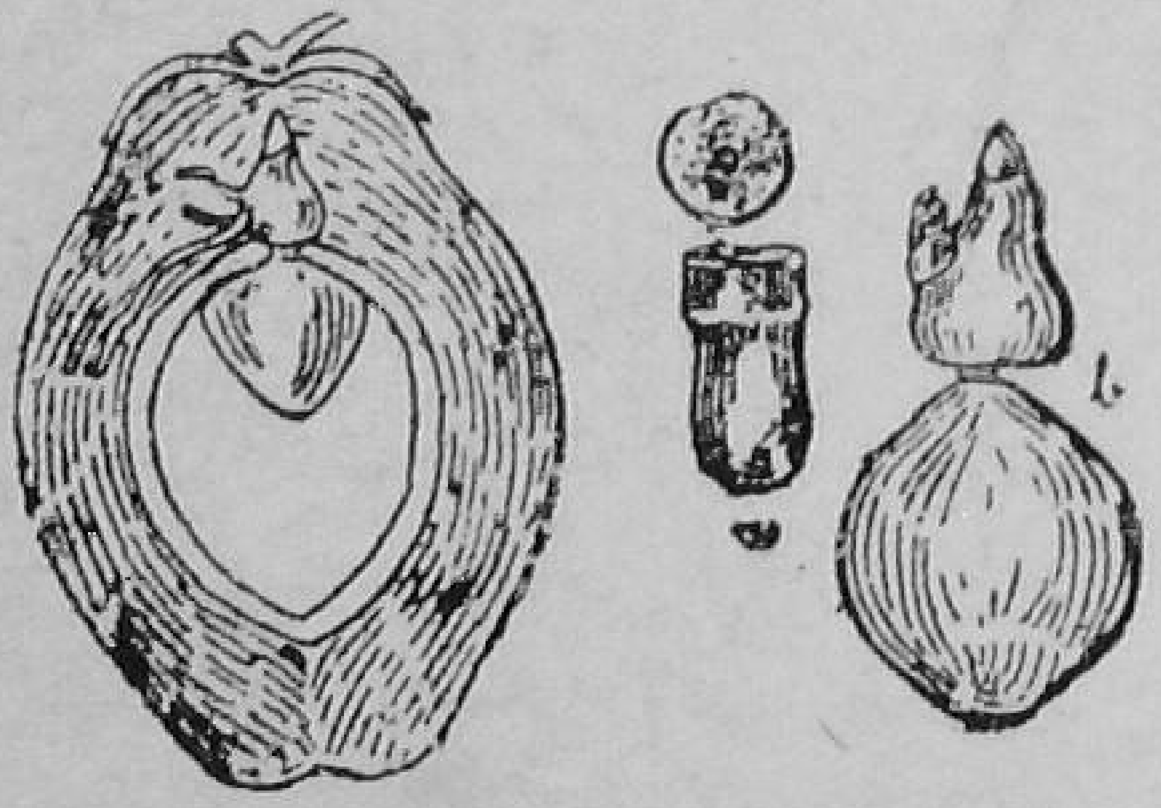


Fig. 13. Embryos of Coconut in different stages of development. Longitudinal section of Coconut showing the developing young plant in position. (*a*) embryo before germination (*b*) Young plant detached.

8. Germination of maize grain (Hypogeal).—In the maize grain during its germination the radicle comes out first piercing the root sheath (**coleorhiza**) and then it grows downwards developing the first root (14). The plumule on the other hand, grows upward with its succession of ensheathing leaves. While still under ground the tip of the plumule protected by **coleoptyle**

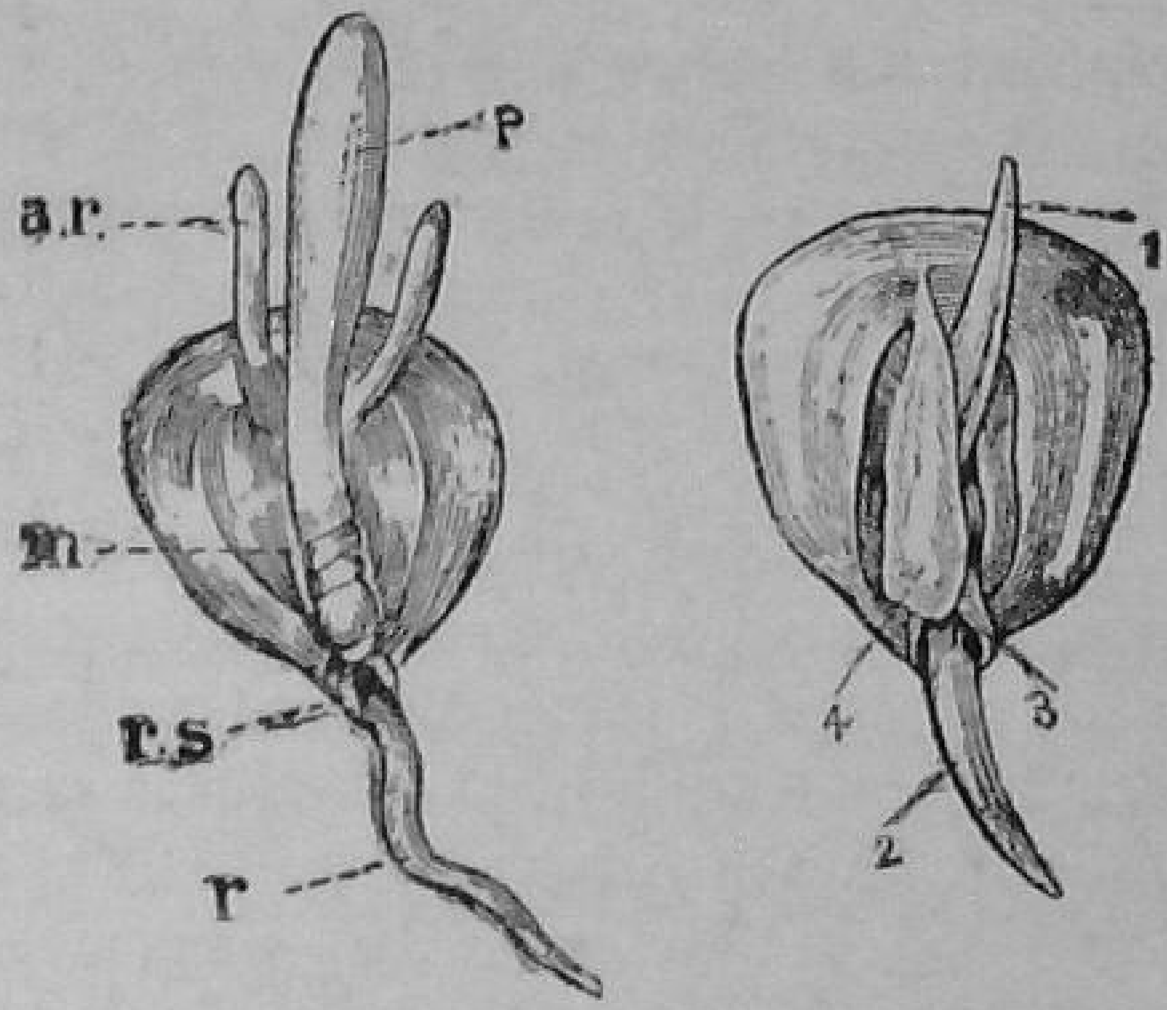


Fig. 14 Miaze seeding. (*P*) plumule. (*ar.*)—adventitious root. (*m*) membrane of seed coats. (*r.s*)—root sheath. (*r*)—radicle.

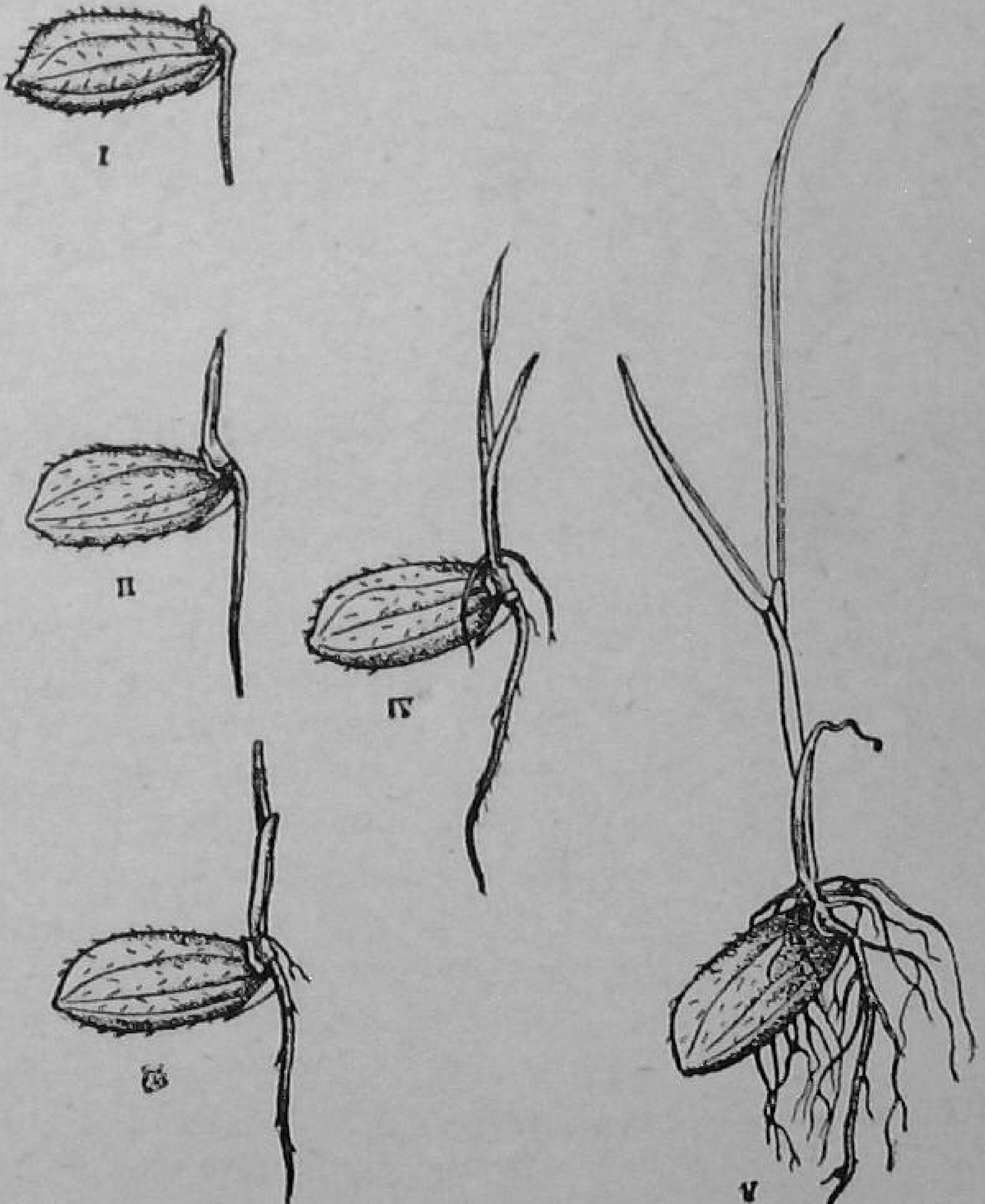


Fig. 15. Rice grain in different stages of germination.

is pointed and firm, and so it is able to push itself up through the soil. The cotyledon is hypogeal. The first root grows downward and very soon new roots arise adventitiously from the axis and these also grow piercing the root sheath and become as large as the first root. The roots in this case are called adventitious roots, because they all arise from the axis and not from the first root.

9. Germination of mangrove seed (Vivipary).—Although a very large majority of seeds remain dormant and pass through a resting stage, it is not an essential condition for germination. There are some seeds that germinate as soon as they are mature while still on the parent plant. The germination of such seeds is described as **Vivipary. In Mangrove plants the seeds pass through the earlier stages of germination while still on the parent plants** and they fall down into the slush below as seedlings only (Fig. 16). The mangrove, *Rhizophora*, produces fruits having two cavities, and out of these two cavities, only one grows and the ovule in it develops into a seed. So only one of the two ovules develops into a seed. The seed is endospermic with an abundance of food material as endosperm. In the embryo we find a cotyledon which is resembling a Phrygian Cap and a hypocotyl with a bud. As germination proceeds the hypocotyl elongates and finally comes out of the fruit. The hypocotyl grows taking food material from the endosperm, and for about nine months it grows, till it is a foot and a half in length and about three ounces in weight. Finally the shoot comes out of the cotyledon and the seedling now falls down into the slushy soil below, where it gets fixed by the growth of adventitious roots. It is not

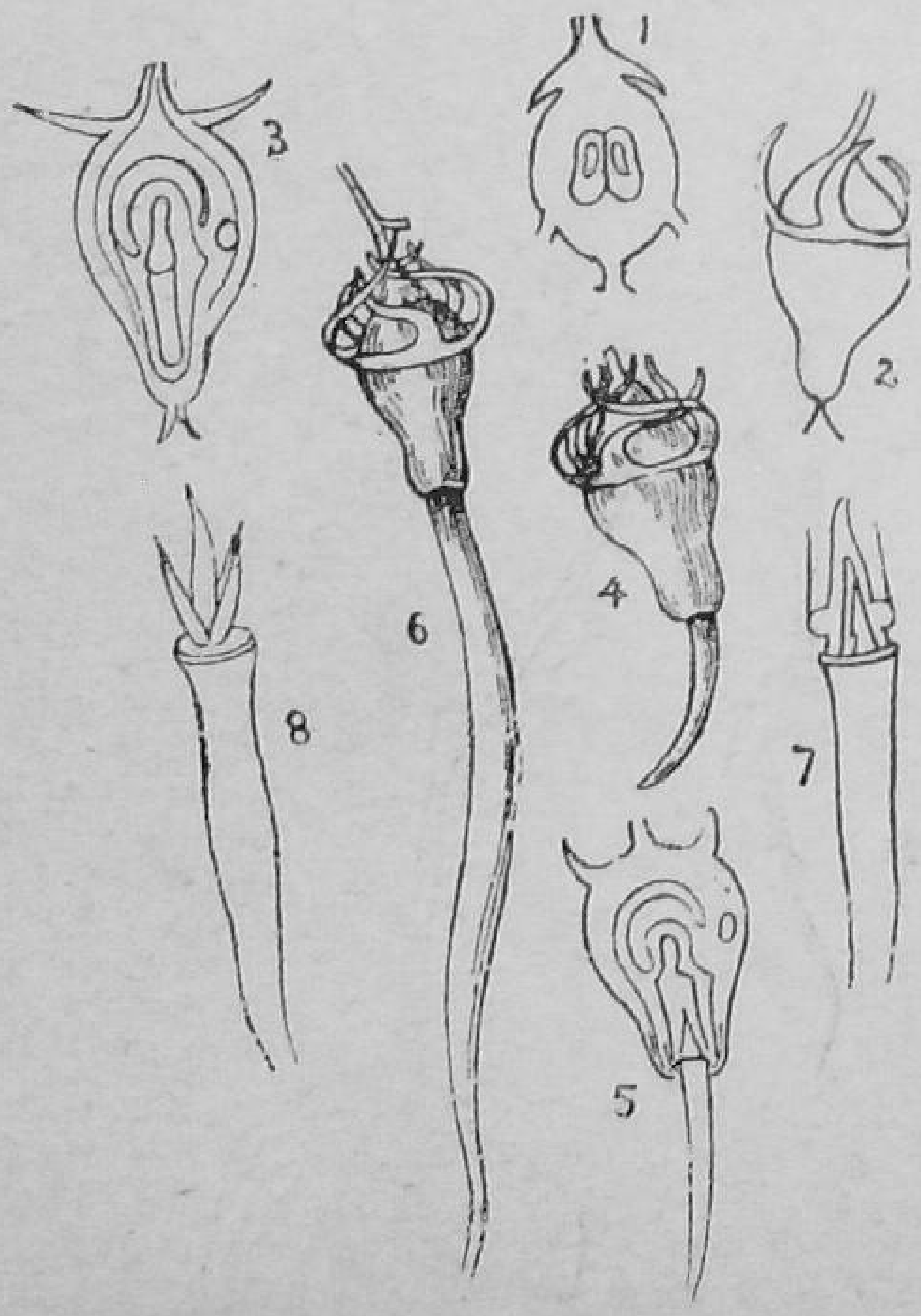


Fig. 16. Mangrove seedlings in fruit. (1) ovary cut through (2) fruit (3) fruit cut through (4) fruit in which germination has just commenced (5) fruit and seedling cut through (6) fruit with advanced seedling (7) and (8) plumule.

also unusual to see grains of ragi germinating in the ear, or seeds of some pulses and papaya germinating in the fruit during wet weather. *Sechium edule* or chow-chow also shows viviparous germination.

As already stated every plant makes a supreme effort towards perpetuating its kind. And in most of the higher flowering plants perpetuation is the work of the seeds. In other words, the seed is an young plant well protected and thrown out by the parent plant, provided with enough food material, so essential for its growth. The need for protection of the embryo or young plant, which is the most important part in all seeds, is indeed very great inasmuch as the conditions outside may not always be favourable. When seeds leave their parents for their travel they contain very little water, and in this dry state they are able to withstand great extremes of heat and cold.

Depending upon their structure and mode of germination, the seeds may be classified as shown in table.

SEEDS.

- Dicotyledonous.
  - Non-endospermic or exalbuminous. e.g. *Dolichos Lablab* (Epigeal). *Cucurbita pepo* (Epigeal). *Arachis hypogea* (Epigeal). *Cicer arietinum* (Hypogeal). *Mangifera indica* (Hypogeal).
  - Endospermic or Albuminous. e.g. *Ricinus communis* (Epigeal).
- Moncotyledonous.
  - Non-endospermic or ex-albuminous. e.g. Orchids.
  - Endospermic or Albuminous. e.g. *Cocos nucifera*. *Zea mays*. *Oryza sativa* (all hypogeal).

Functions of the Cotyledons.

Cotyledons are seed leaves. They serve different purposes in different plants. In *Dolichos lablab*, they are thick and stout. Starch and protein which are the reserve food for the embryo here, are stored in them. During germination, the cotyledons are pushed out of the soil. As the stored food gets slowly exhausted the cotyledons shrink in size. When they are fully exposed to light they turn green. When finally all the stored food is exhausted, the shrunken cotyledons are shed.

In pumpkin the cotyledons are not so stout as in *Dolichos*. During germination the cotyledons come out of the soil, increase a little in size and turn green. But soon they wither and are shed.

In castor, the reserve food is stored in the endosperm. The cotyledons are thin and membranous and show prominent venation. When the seed germinates the cotyledons are pushed out of the soil. They increase in size, turn green and appear like normal leaves. They function like leaves for some time until some more leaves are developed in the seedling and then they wither and are shed.

In *Cicer* and mango, the cotyledons are stout and function as store house for the reserve food. When the seed germinates they remain in the soil. As the seedling grows, they shrink and fall out.

In date and palmyra palm seeds, the cotyledon is the first to emerge out as a sheath enclosing at its end the primary axis. One end of the cotyledon enlarges as a sucker inside the seed and the other end elongates and pierces the soil carrying at its tip the primary axis. When the cotyledonary sheath has grown sufficiently, the plumule grows upwards and the radicle downwards by piercing this cotyledonary sheath. The cotyledon of the *Crinum* seed also functions similarly.

In coconut, the upper end of the cotyledon pushes the primary axis out of the hard shell. Then the plumule and radicle pierce the cotyledon and grow upwards and downwards respectively. The lower end of the cotyledon increases in size enormously and fills the entire cavity. It is spongelike and acts as a powerful absorbing organ. It dissolves the reserve food in the endosperm, absorbs it and transmits the same to the growing seedling.

In maize, the cotyledon does not very much increase in size. The primary axis is enclosed laterally by it. That portion of the cotyledon which is in contact with the endosperm secretes enzymes during germination of the seed. It also acts as an absorbing organ and transmits the food material from endosperm to the growing plumule and radicle.

Optimum conditions for germination.—For successful germination, certain external conditions are very necessary. **These are the presence of water, oxygen, and a certain degree of heat.** (1) Without water germination cannot begin because, it is necessary not only to stretch the tissues of the embryo inside, but it has also to serve as the solvent for the reserve food-materials. Seeds absorb large quantities of water, each taking in as much

as hundred times its own weight; and this water stretches the tissues with a force equal to about two hundred pounds per square inch. (2) The presence of oxygen is also essential. In its absence seeds fail to germinate even if the other two conditions exist. Oxygen seems to be necessary for the physiological process of respiration by means of which energy is made available and also to help in the formation of new diffusible compounds from the reserve material. (3) Although some seeds are known to germinate at very low temperatures, a very large number of them require a temperature between 15 to 25°C. Since germination is really the initiation and the continuation of growth, a certain amount of energy in the form of heat seems to be essential. (4) It should not be forgotten that for successful germination certain internal conditions must also be favourable. The parts of the embryo should be in mature condition and the tissues must contain the special digestive ferments, so necessary in rendering the reserve material diffusible.

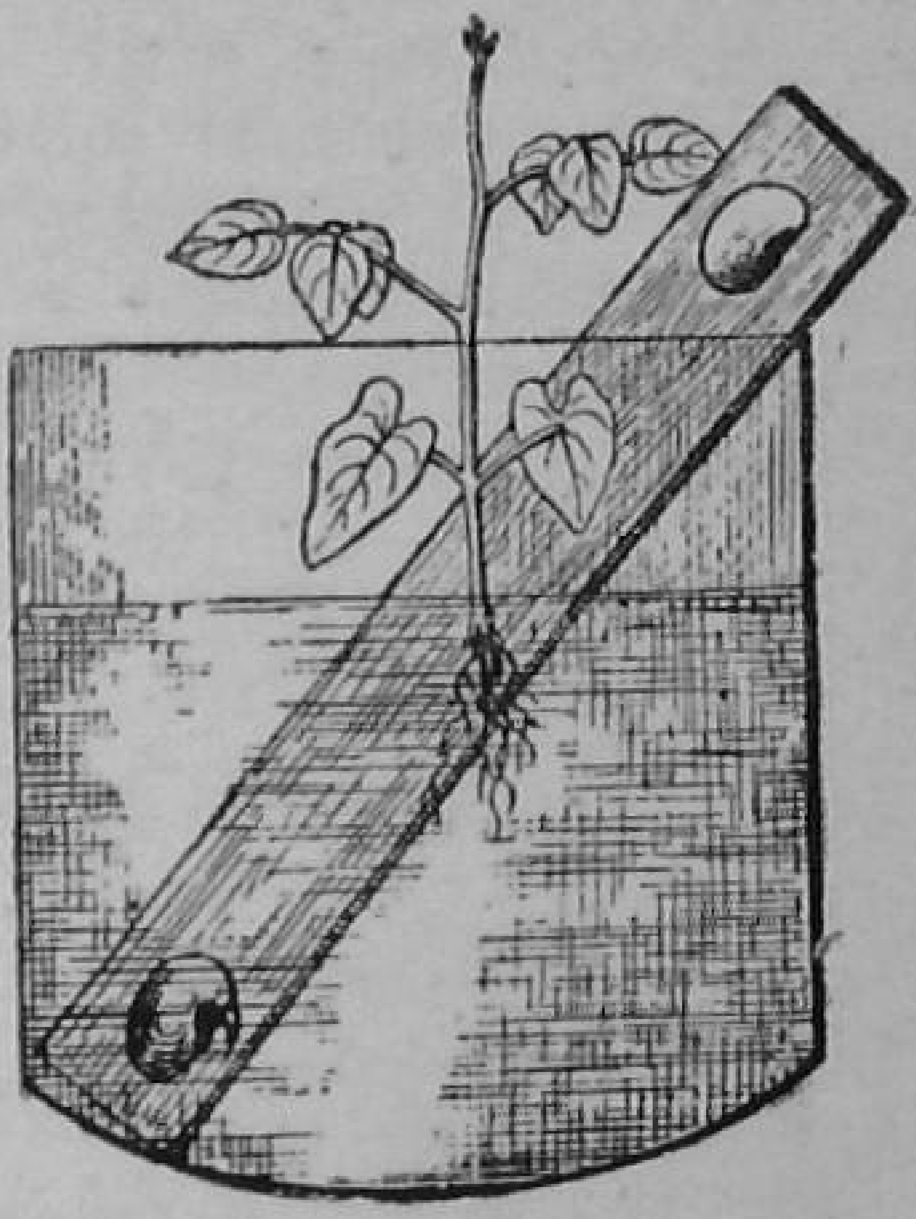


Fig. 17. Three-bean experiment.

Three-beans Experiment.—To show that water, oxygen and temperature are essential for germination, an experiment as diagrammatically shown in (fig. 17,) may be performed. Fill a beaker half-full with boiled and cooled water. Take a narrow piece of plank and fix on to it three bean seeds at three different levels as shown in fig. 17. The piece of wood is placed in a beaker. One of the seeds is fully submerged in the water, the second seed is just touching the surface of water and the third is at high level out of contact with water. In a few days time it will be seen that the middle seed germinates and grows vigorously into a seedling while the one submerged in water just germinates but cannot grow up. The third seed with no contact with water does not germinate at all.

The submerged seed germinates but does not grow because it has no sufficient supply of oxygen. The middle seed grows because it has water, oxygen and temperature in optimum conditions. The top seed does not grow because it has no water even though the required temperature and oxygen are available.

Stored food in seeds.

When the radicle peeps out through the slit in the seed-coat, we may say that germination has begun, and this process is considered to have ended when the seedling has produced green leaves. During the period of germination several changes occur and some of them are visible, while others are not. The growth and increase in size of the various parts of the embryo and the appearance of new parts such as the formation of root and leaves are visible, but the changes occurring in the reserve material cannot be seen. It is obvious that the reserve material is being largely utilised during the process of germination.

From a knowledge of the structure of seeds already considered, we learn that reserve material is stored up in all seeds and that in some seeds this substance is stored in the embryo itself, i.e., in the cotyledons, whilst in others just outside the embryo, i.e., in endosperm. The reserve material is generally found in the form of starch in most seeds, although it occurs as oil in castor, gingelly, groundnut and *Carthamus tinctorius* seeds and as hard cellulose in Date seeds. Mixed up with the starch small quantities of proteins also are found. Whatever the form of the reserve material it is usually insoluble in water. Before this can be used, it must be rendered soluble in water. In the cotyledons and in the endosperm certain special substances are formed in the cells, and as soon as water gains access to these parts these special substances called enzymes, render the reserve material soluble in water. As the reserve stuff varies in nature, there are different kinds of ferments acting on

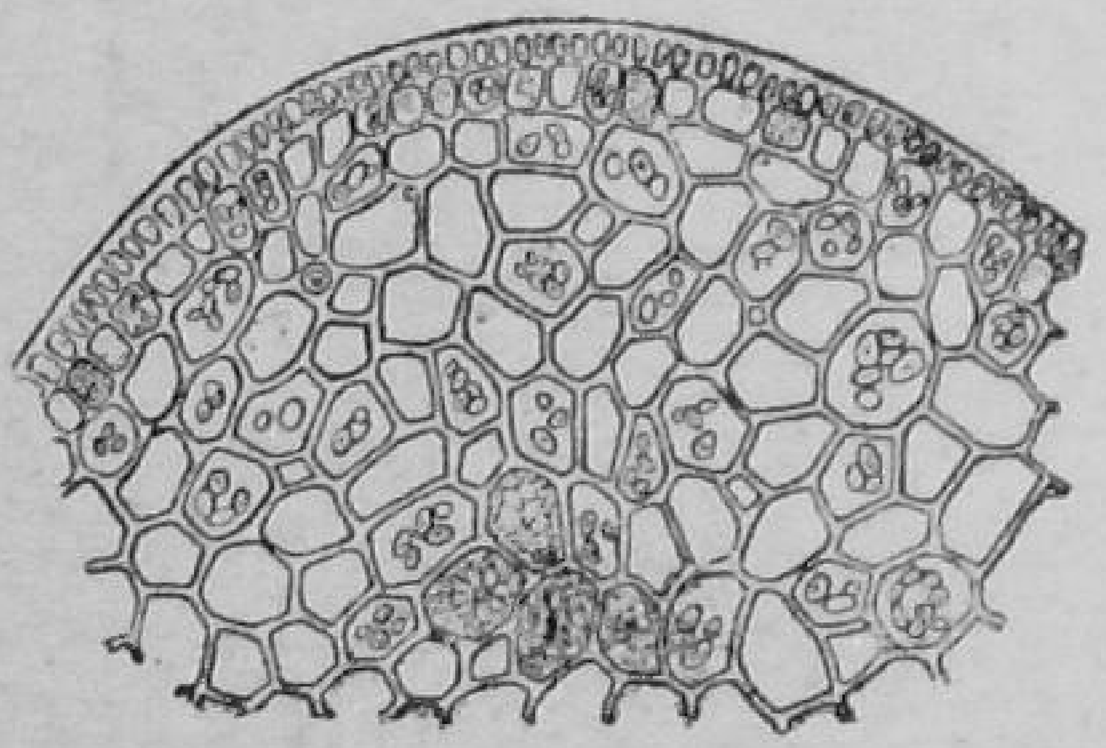


Fig. 18. Starch grains in the cells of the cotyledons of *Dolichos lab-lab*.

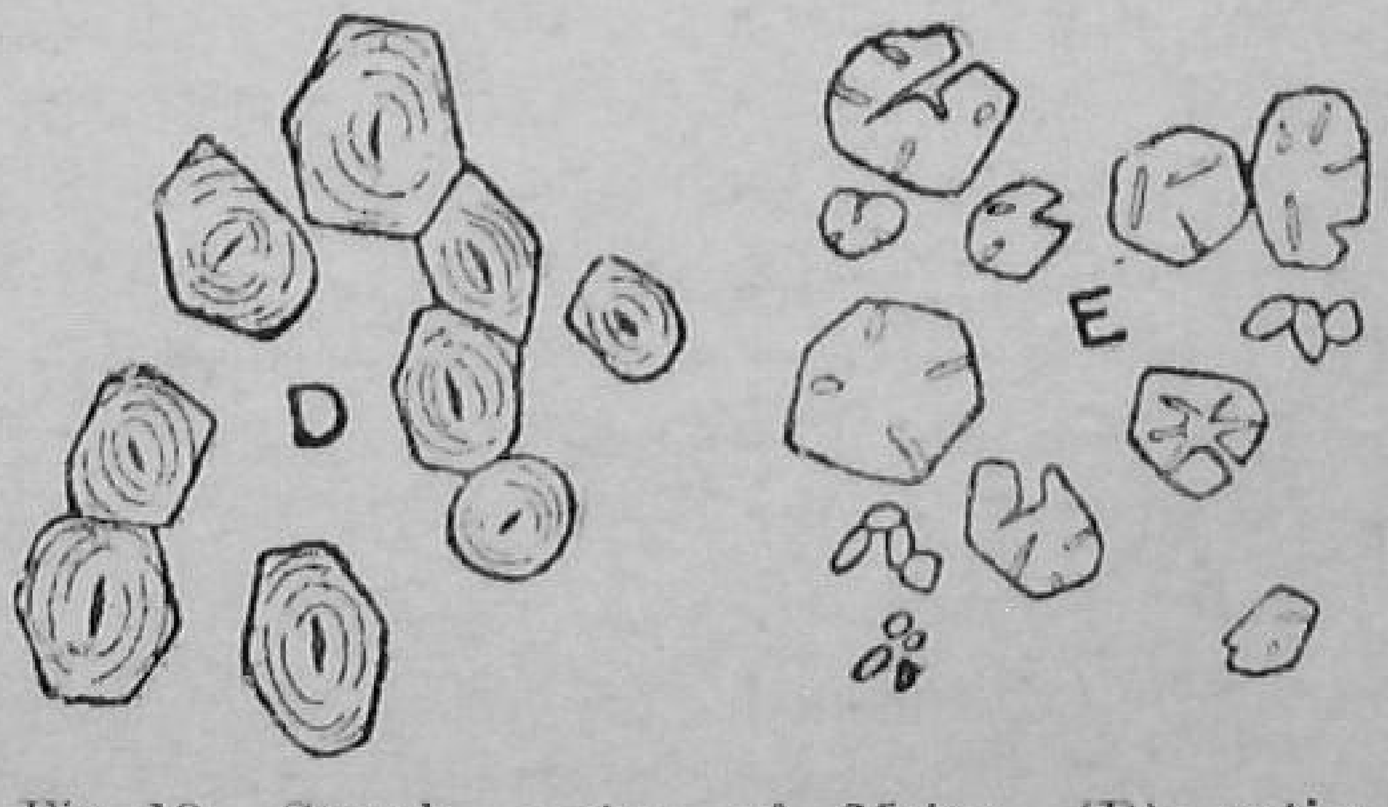


Fig. 19. Starch grains of Maize. (D)—entire starch grains in the endosperm; (E)—the same but corroded.

these different reserve materials. The enzyme acting on starch is called **diastase.** These enzymes can act only when water is present. Thus it is clear that water is necessary, not only to stretch the tissues and bring about the escape of the plant, but also to rouse the activity of the embryo and serve to take the food material in a soluble form to various parts to enable them to grow.

The presence of starch in the cotyledons or in the endosperm can be made out with perfect ease. If slices of cotyledon or endosperm be rubbed in water and the water allowed to stand, a fine white powder consisting of starch grains is precipitated. When a grain of maize or cholam is split longitudinally into two halves and the two halves are put in an aqueous solution of iodine, one portion becomes dark blue and another portion remains yellowish brown. The dark portion is the endosperm mostly consisting of starch and the brownish part is the embryo without any starch in it. The common test for starch is iodine test. When starch comes into contact with a watery solution of iodine it becomes blue or purplish blue.

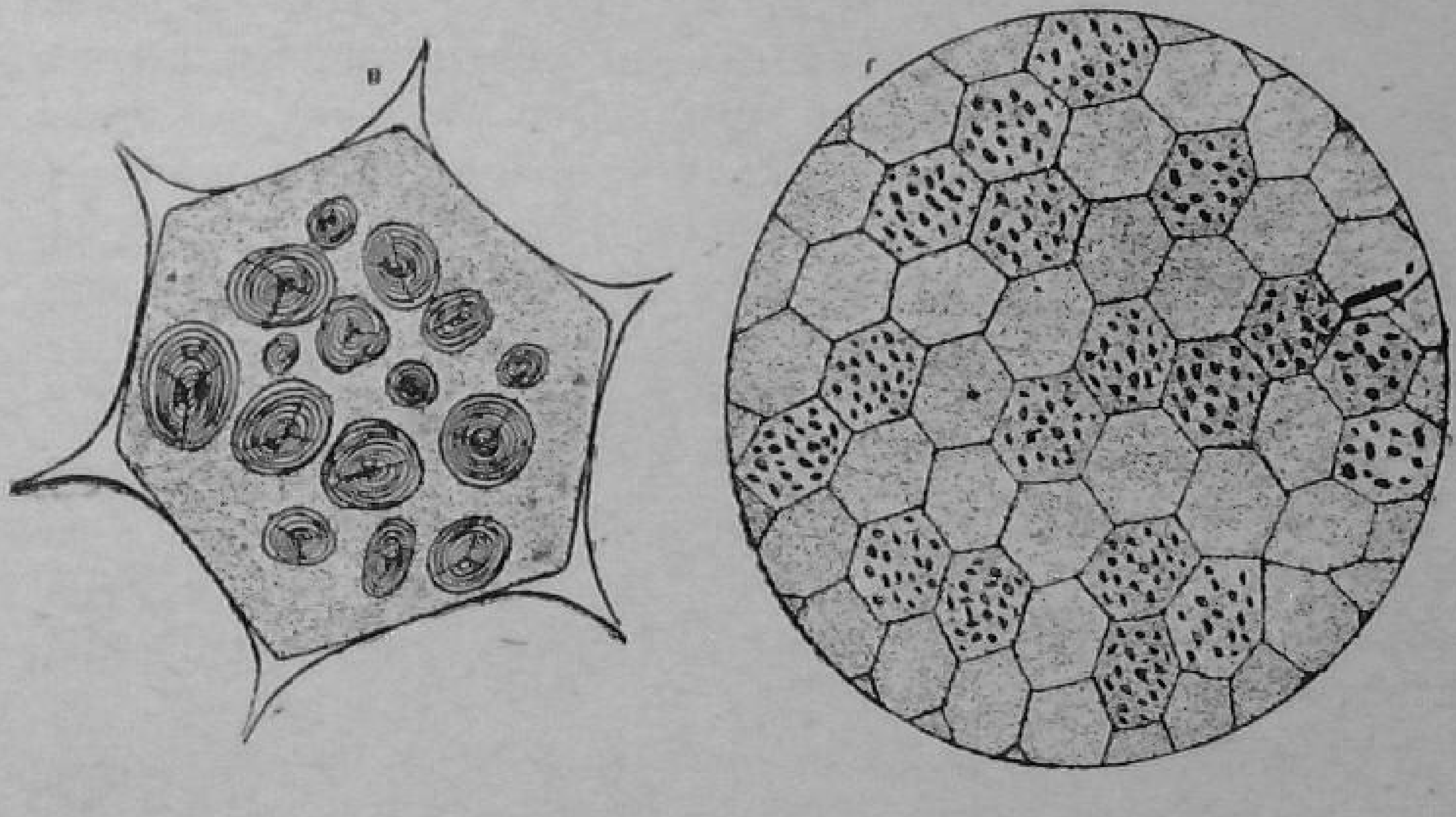


Fig. 20. Cells in the cotyledon of a seed. (Left) a single cell with starch grains; (right) cells filled with starch.

The cotyledons and the endosperm of seeds really consist of very small compartments or chambers of different sizes and shapes. Each of these compartments is called a cell. All the cells of the cotyledon and endosperm are filled with starch grains and these cannot pass from one cell into another, because the cells are closed on all sides. It is only when starch is rendered soluble and dissolved in water that it can pass through membranes of cells. As a matter of fact, all parts of plants are made up of cells. Cells,

their nature, modifications and their arrangement into tissues, etc., are dealt with in the section of Histology.

Dormancy.

Seed is in a suspended state of animation. Generally, stored seeds contain 5—10% moisture. Life activities such as respiration are in progress at a very low rate. The seed in fact is a living plant in **dormant state.**

Some seeds germinate immediately after harvest, and some others do not germinate immediately but require a period of rest before they germinate. In the latter type of seeds, some series of changes take place inside the seeds and this is described as "**after-ripening**" of seeds. Seeds of paddy, cholam, ragi, cotton and mango do not generally require rest. They germinate immediately after harvest. Seeds of wild indigo and *Datura* require period of dormancy. Different plants behave differently in this respect.

Seed-testing.

Before sowing seeds in the field one must know whether seeds are capable of germinating and growing into vigorous plants, i.e., the **viability** or germinating capacity of seeds is to be tested. Immature seeds do not germinate. Conditions of storage largely affect the viability. Under bad conditions of storage, as storage in moist places or exposure to excessive heat, the seeds soon lose their power of germination. Even under ideal conditions of storage, the seeds gradually lose their viability. Some seeds with very hard coat as in most of the Leguminous seeds are viable even after long periods of storage.

It is therefore necessary to test their viability before seeds are sown in the field. This test may be carried out as indicated below.

Representative samples of seeds are drawn from storage. They are soaked in water for 6 hours. 100 seeds are counted and placed well spread over the moist blotting paper in a germination tray. The tray contains water and keeps the blotting paper moist. The whole tray is then placed inside an incubator which maintains temperature range between 30°—35° C. The doors are closed to cut off light. The number of seeds that germinate is counted daily until no more seeds germinate. The number of seeds that germinates out of 100 gives the germination percentage. The lower the germination percentage, the higher is the seed rate that must be adopted to get a good stand of crop in the field.

CHAPTER IV

ROOT

A plant grows attached to the soil and consequently must have certain parts fixing it firmly to the ground. The underground part of the plant is concerned with the fixation of the plant and it consists of many roots. The whole of the roots of a plant is called its **root system.**

A plant begins its existence as an individual from its embryonic stage in the seed. In the embryo the plant body or **cormus,** as it is sometimes called, consists of the primary axis and the cotyledons. This young plant grows at the expense of the reserve material in the seed, becomes fixed to the soil and very soon begins its career as an independent plant. If it is to thrive as an organism, it must get itself first established in the soil in such a way that it can make use of materials available in the soil, besides securing a firm anchorage. As a matter of fact, the cormus becomes differentiated into the fundamental organs, the shoot and the root. For the development of the shoot, the plant must first secure a foothold in the soil and for this the roots must develop first. From a study of the development and growth of the seedlings from the commencement of the germination of seeds, we know that the part which develops always first is the root (Fig. 21).

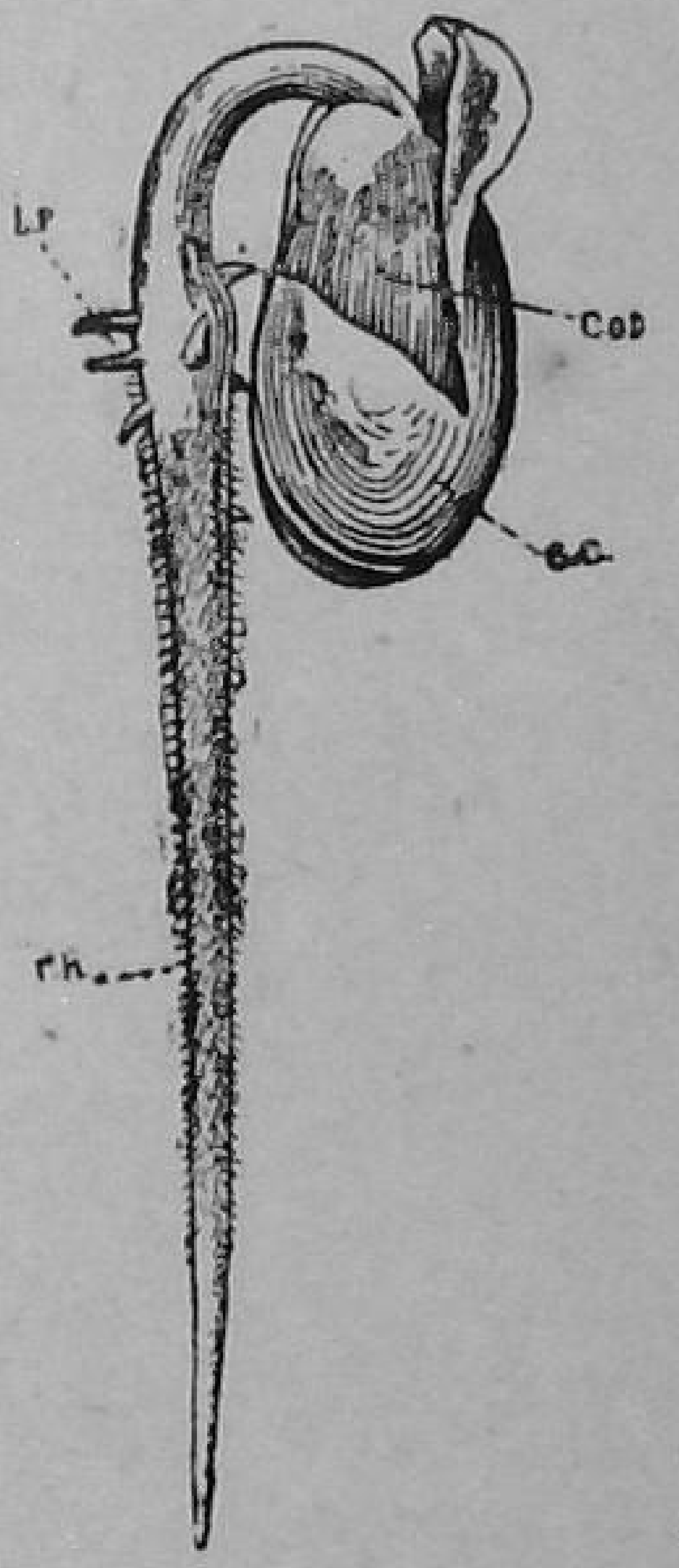


Fig. 21 Seedling of *Dolichos lablab* (*cot*) cotyledon; (*l. r.*) lateral root; (*s. c.*) seed coat; (*r. h.*) root hairs.

The Root-system of a plant

(*a*) Normal type

If we examine the root system of a well developed seedling of *Dolichos Lablab* or *Ricinus communis* we clearly see that it consists of a leading central root which grows vertically downwards and a number of lateral roots all arising from it and growing sideways in different

directions. The central root is termed the **primary root** and the branches **lateral roots.** The lateral roots are disposed around the primary or the tap-root in four distinct rows. In most of the dicotyledonous plants, the main root forms the downward continuation of the main stem and grows vertically down into the soil. From this tap-root spring lateral roots of the first order which penetrate the soil obliquely or horizontally. On the lateral roots of the first order those of the second order arise and this branching

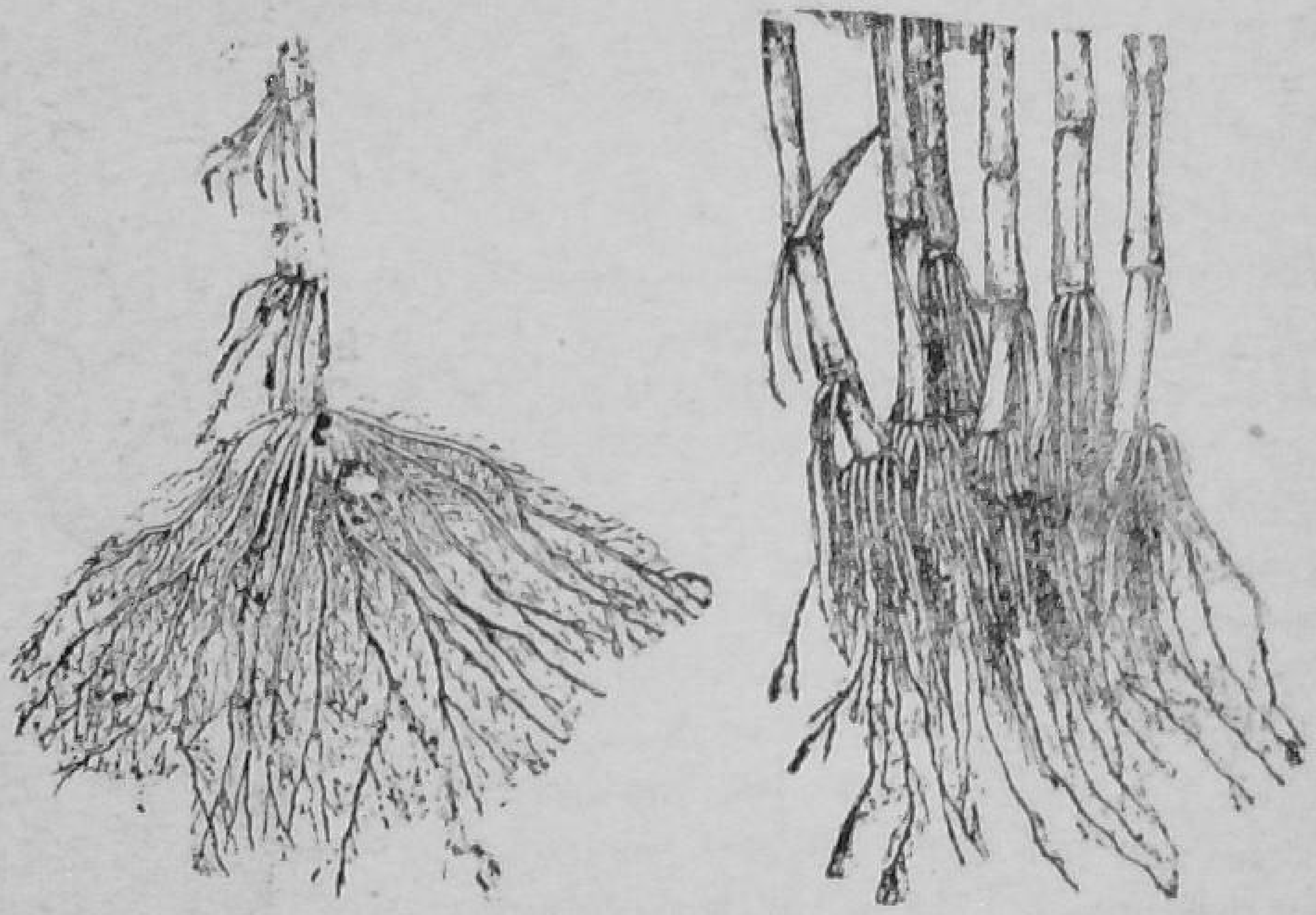


Fig. 22. Adventitious roots of cholam.

goes on in succession. As a result of this kind of development, the roots of successively higher orders are thinner and they grow less strongly than the roots from which they arise. The branches of the root system ramify the soil in all directions as uniformly as possible and, as branchings continue, do not leave even a cubic inch of soil unused. The root-system above described is typically racemose. A root system in which all the roots are directly or indirectly connected with the main root, may be considered to be a **normal type** of root system.

(*b*) **Adventitious root system**

In Monocotyledonous plants a tap-root is usually wanting, because the first formed root becomes arrested. Numerous roots arise from the base of the stem and get into the soil vertically, obliquely or horizontally (Fig. 22). All these roots bear lateral roots of successively higher orders which penetrate the soil in all directions. In plants like Cholam, Maize and other cereal plants numerous roots, all more or less of the same size, grow from the

nodes at the base of the stem. Such roots as these are called **adventitious roots.** All grasses and plants having creeping or underground stems, and cuttings, produce adventitious roots.

Adventitious roots may be classified as follows :—

Fig. 23. Stilt roots of *Pandanus.*

1. **Prop or Stilt roots.**—In *Pandanus* and the Banyan, roots arise from the stems and they all grow downward and get into the soil after growing some time as ærial roots. Such roots are called prop or stilt roots for the reason that they form strong supports, (Fig. 23.)

2. **Climbing roots.**—Pepper, Betel, and Pothos and such other climbing plants have roots springing from the stem. These roots enable these plants to claim and grow well on supports, (Fig. 24).

3. **Aerial roots.**—Certain Orchids as for e.g., *Vanda Roxburghii* produce roots which grow on other plants, but they never penetrate into them. These ærial roots are those of **epiphytes.** These roots are called **Velamen** roots. They are thin, papery outside with numerous minute pores with which they absorb moisture from the atmosphere. They contain chloroplasts and function like leaves and manufacture carbohydrates.

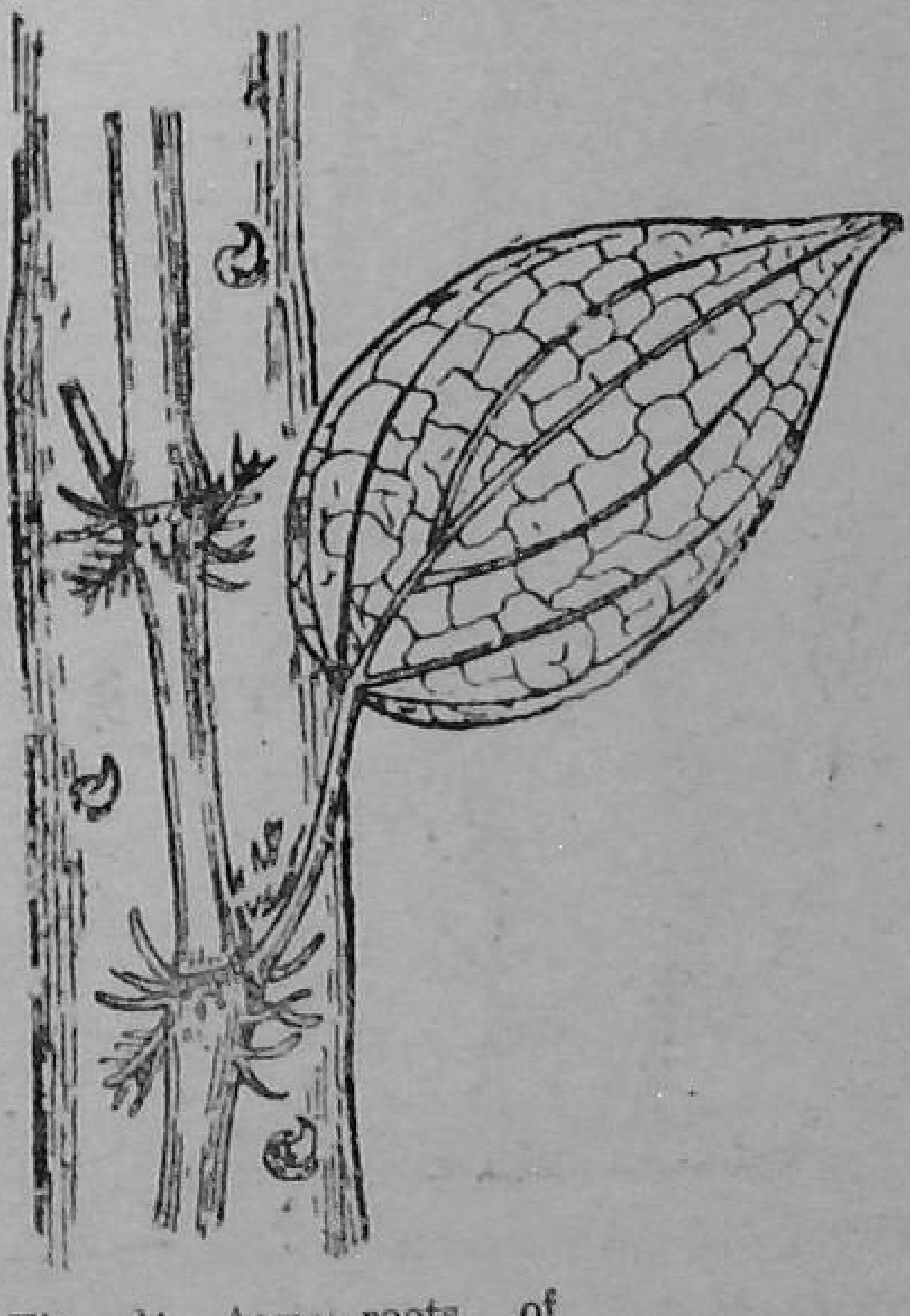


Fig. 24. Aerial roots of pepper vine.

Fig. 25. Leaf-roots of *Bryophyllum*.

4. **Leaf-roots.**—Sometimes roots develop from leaves. Some of the plants such as *Begonia* and *Bryophyllum* when injured produce buds either in the cut places of the veins of the leaf (ribs) or in the margin of the leaf. These buds develop roots also in large numbers, (Fig. 25).

5. **Respiratory roots.**—Some plants such as *Avicennia* growing in marshes produce respiratory roots, (Fig. 26.)

6. **Floating roots.**—Some aquatic plants produce adventitious roots from their nodes, as in *Jussiaeu.*

7. **Parasitic roots.**—(Sucking roots) *Loranthus* and *Viscum* have such roots. These are called **haustoria**. *Santalum*, *Cuscuta* and *Orobanche* have also **haustoria.**

8. Adventitious roots are found in *Cucurbita*, Rose, *Moringa*, grafted mango, guava and many fruit trees. These roots arise from the cut ends of the stem.

Fig. 26. Respiratory roots of *Avicennia*.

Parts of a growing root.

If we examine the root of a young bean seedling, we can distinguish in it distinct parts. The free end of the root is naked and smooth externally, with its stiff and pointed end covered by a **root-cap** or **calyptra**. This part is the growing portion of the root. In most cases the presence of the root-cap cannot be made out with the naked eye, and without the use of a microscope. However, there are a few instances of roots in which the root-cap can be seen easily with the naked eye, as in the aerial roots of *Pandanus* and Banyan. (Fig. 27). Behind this portion comes the region of the

root which is covered with root-hairs. The root hair region lies in front of the older portions of the root.

The growing portion of the root really consists of two distinct regions. The extreme tip covered by the root-cap is one and the other region is that part of the root lying between the root tip and the root hair region. The extreme tip is a very delicate part consisting of young actively dividing cells, and this is the actual growing point. During the elongation of the root-tip, the outer surface of the root cap gradually wears away and becomes mucilaginous, so that the root-tip glides easily between the particles of the earth. As the root cap wears away in front, new tissue is continually formed from the growing point behind, and thus the root-cap remains of almost constant thickness. The region of the growing part of the root lying behind the root tip, is the region where growth in length is most active.

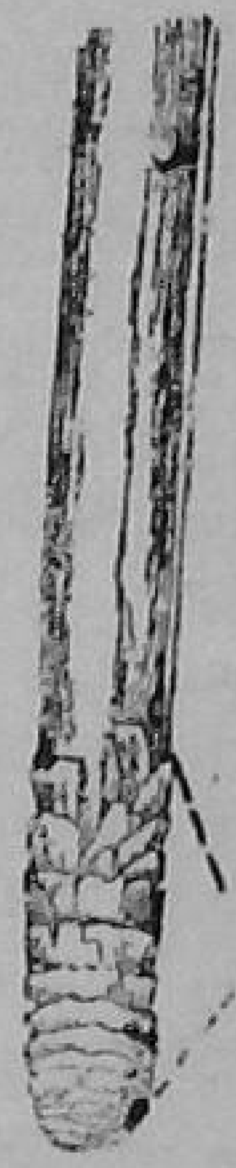


Fig. 27. Root-tip of *Pandanus* (R.C.) root-cap.

The root hair region, as already stated, occurs just above the elongating portion of the root. So long as the root is elongating, no root hairs develop from its surface. But as soon as growth in length ceases in roots, root hairs begin to develop from their surface. The advantage of this becomes clear if we remember that the function of these hairs is to absorb water from the soil. This function cannot be performed if the position of the root hairs were continually altering with the growth of the root. Furthermore, under such conditions the delicate root hairs would be torn and become useless. The root hairs grow between the small particles of the soil, with many of which they come into very close contact.

Functions of root

The chief functions of roots are **fixation, absorption and conduction.**—The root system would be able to absorb water only if the plant is firmly fixed to the soil. Every part of the root system is concerned in this work of anchoring the plant to the soil. The root hairs adhere firmly to the soil particles, thus constituting ever so many hold-fasts. The tap root grows down vertically and the lateral roots and their branches grow in all directions around the tap root. These therefore support the plant in a splendid manner.

The root hairs which are microscopic in size are in intimate contact with the soil particles. They absorb moisture and salts in solution. These are then conducted through the various tissues

and finally into the conducting vessels of the root. From there, the raw food materials are taken to the leaves where they serve as materials for the manufacture of the various food materials of the plant.

The size of Root systems

The root-systems of plants vary to a considerable extent and their nature and extent depend very largely upon the environment. The texture of the soil and the amount of moisture in it are the factors that influence the development of the root-system. Plants growing in a heavy compact soil cannot be expected to have a very extensive root system, but in an open loose sandy soil it will be very much larger.

The total length of all the roots of a plant would generally be very surprising. The root system of even a cereal plant, such as paddy or wheat for instance, will be several yards in length, when the roots are placed end to end. According to the investigations of certain botanists, the root system of an oat-plant measured one hundred and fifty yards or so in length, although the spread of the root system was only a cubic yard or two. The root system of a pumpkin plant is said by Nobbe to have measured five kilometres (about 5000 yards).

Roots, in order to meet the demands of a plant for absorption and anchorage, must go deep enough and spread far enough laterally. A tree would naturally require a deeper and more extensive root-system than a herb. Roots are capable of growing to any length and there is no limitation for their growth. The development of the root system and that of the shoot system are intimately related to one another. For an increase in the root system, a supply of organic materials is necessary, and this depends upon the leaves in the shoot. Again the increase in the shoot makes great demands on the water-supply from the roots, and this can only be met by the increase in the surface of the root system. In other words, the root system must develop more branches.

In all ordinary plants even including some trees the tendency of the root system is to increase the extent laterally rather than downwards because more of the requisite mineral matter is available nearer the surface of the soil than deeper down. Furthermore the upper layers of the soil are better aerated than the deeper layers and contain more water.

The roots of most cereals do not extend to more than four of five feet. Some have roots with greater lateral extension than others. In large trees such as the tamarind and the Rain tree

the lateral roots may reach a length of 150 to 200 feet, but the depth to which they go is never so much. The lateral roots of these two trees grow along maintaining an average depth of not more than three or four feet. Roots of some trees, such as those of *Albizzia lebbek* and *Acacia arabica*, go rather deep and sometimes their tap-roots go very deep, twenty feet or more.

In the case of certain trees growing in tropical forests the stems are rather high and very thick. Some of these trees are supported at the base of the trunk by very strong vertically placed **buttress-root.** As examples we may mention the trees of the genera *Bassia*, *Vateria* and *Terminalia*.

Distinction bewteen stem and root

From the beginning root grows downwards into the soil and seeks darkness while the shoot grows upwards and seeks light. Their appearances are also different. The green colour so characteristic of the aerial shoots and leaves is absent in the root system. The shoot system bears on the axis two kinds of lateral members, branches and leaves, whilst the root system has only one kind of appendage, the lateral roots. The leaves arise at distinct points on the stem termed nodes and successive nodes are separated by internodes. There are buds at the axils of leaves on the shoot and none are found normally in roots. These buds are superficial outgrowths from the axis, i.e., they are exogenous. But in the roots, lateral roots do not arise from the outer portion but they spring from the deep seated parts of the main root and push themselves out, i.e., they are endogenous (Fig. 28). The free ends of all roots are covered by root caps.

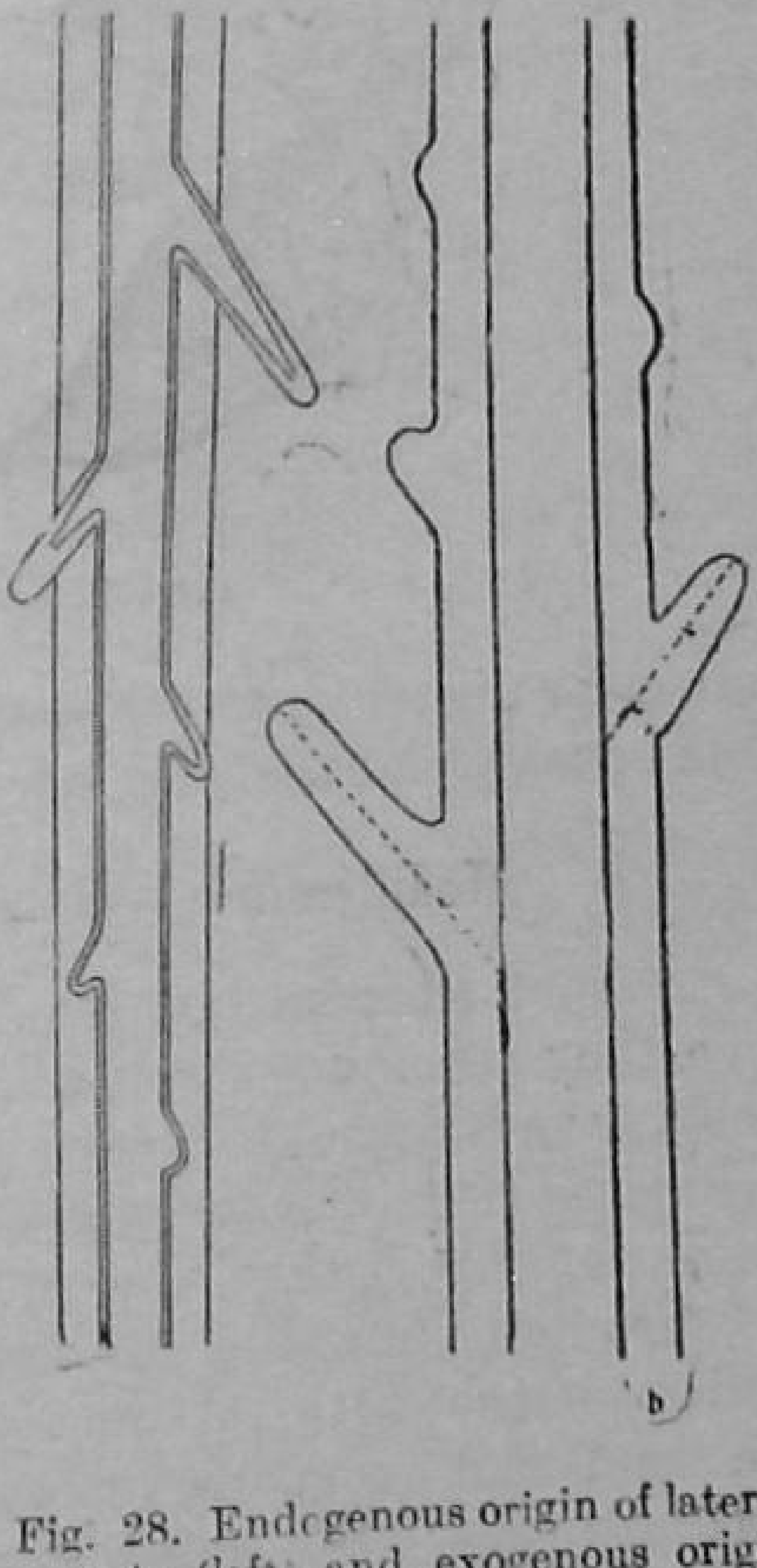


Fig. 28. Endogenous origin of lateral roots (left; and exogenous origin of lateral branches (right).

It is true that roots do not normally bear buds, but when they are injured adventitious buds are formed on them. When the underground roots of *Ficus religiosa* (Peepul tree), *Azadirachta indica* (Margosa tree), *Clerodendron*, *Millingtonia hortensis* (Indian cork tree), *Odina wodier*, and

Ixora coccinea are severed, adventitious buds arise from the roots which are called " **root suckers** ". Sweet Potato root tubers bear adventitious buds and the tubers are sometimes planted out in the field to raise a crop (Fig. 29). When the roots of guava are

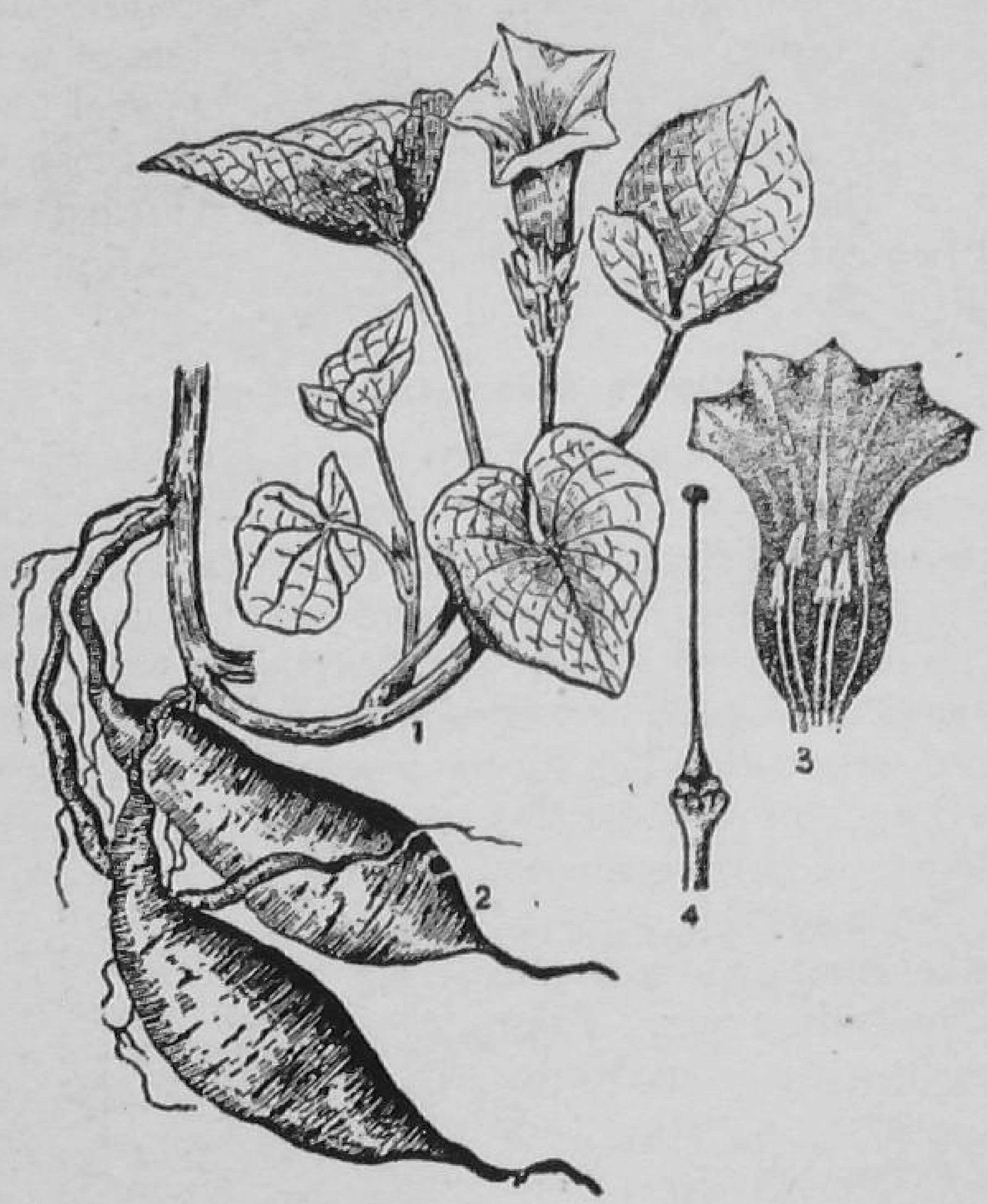


Fig. 29. Sweet potato tuber.

pruned by digging a trench round the base of the plant, numerous young guava plants spring up in the trench on the distant side.

Modifications and special functions of roots.

So long as roots continue to perform their normal functions only, they are uniform and do not present any great modification. Roots are not without diversity in form and size, but compared with modifications in leaves and stems they are far less varied. The reason for this is that the conditions under which the roots grow are far more uniform. However much be the variations upon the surface of the earth, the conditions for life in the soil are much the same all over the world. When roots have to perform functions other than absorption and fixation, they present certain modifications. For example, in the case of plants such as radish,

sweet potato and certain species of orchids, the roots, so long as they are young, perform their normal duties, but later on they

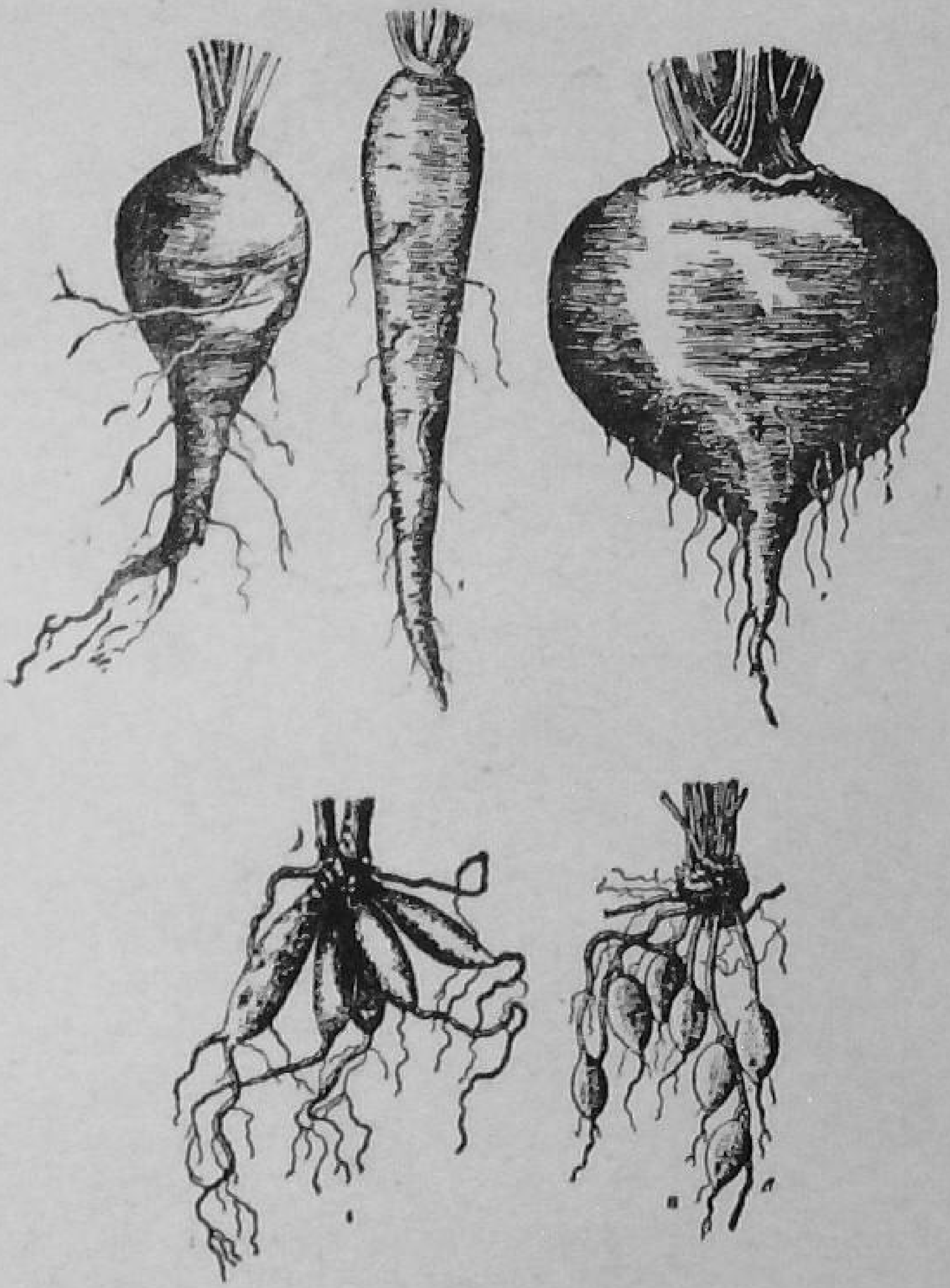


Fig. 30. Modified roots (top row)—fusiform, conical and napiform roots (bottom row) tuberculaı and nodulose-roots.

become swollen, because of the storage of reserved food materials. Roots modified in this manner are called **root tubers.** (Fig. 30, 31).

Roots that are swollen on account of storage of food material may assume different forms. They are **fusiform** or spindle shaped, if swollen in the middle and tapering at both ends, e.g., radish; **napiform** when considerably swollen at the upper part becoming almost spherical and sharply tapering at the lower end, e.g., Turnip and Beet; **conical** when generally tapering from base to apex like a cone, e.g., Carrot; **tubercular** when there is a cluster of succulent roots, e.g., Dahlia and Asparagus; **nodulose** when the root becomes suddenly swollen near its apex as in some sedges; **moniliform or beaded** when there are small swellings at frequent intervals, as in some grasses. (Fig. 32).

Roots of the plants are usually situated in the soil. But there are also plants whose roots are exposed to the atmosphere. These

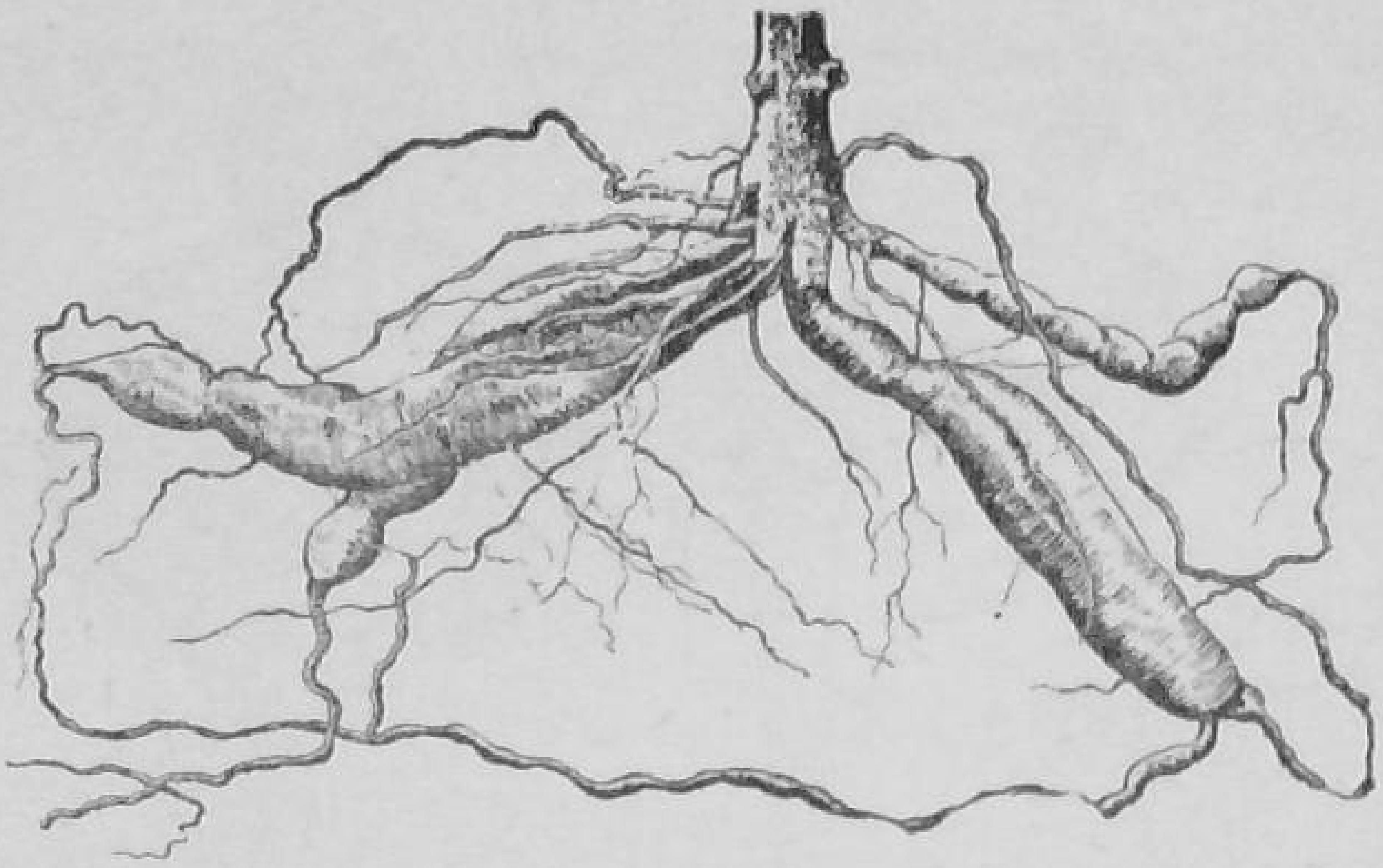
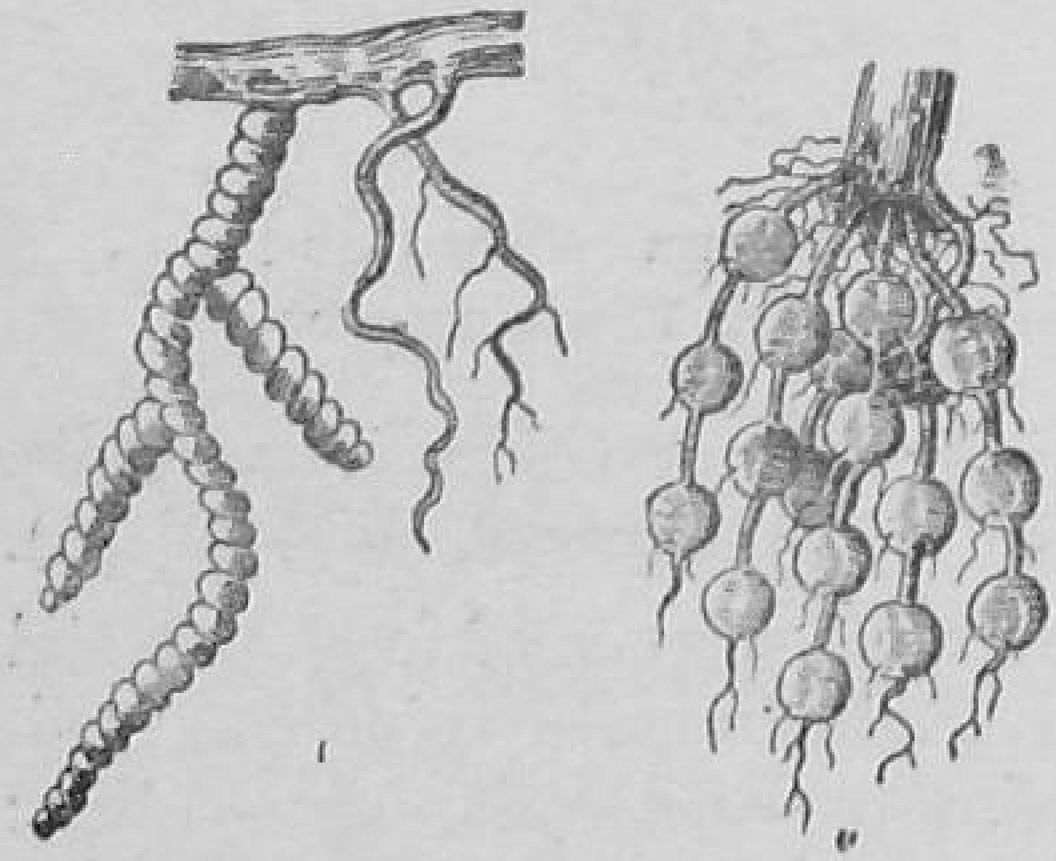


Fig. 31. Root tubers of tapioca.

are called **aerial roots.** (Figs. 22, 23). In some plants these aerial roots remain always in the air, whilst in a few others they remain so for a short time only and then penetrate into the soil. Such aerial roots prop up the plants after entering the ground and this may be seen in the Cholam plant, the Pandanus and the Banyan tree. After penetration into the soil, these aerial roots behave just like the ordinary underground roots.

The aerial roots of the Banyan tree are well known and they are also of peculiar interest. (Fig. 33). These roots remain in the air for a fairly long time, but they grow in length gradually and in the end penetrate the soil. After getting into the soil these roots grow in thickness and afford props to branches of the shoot system. In the seedling stage the Banyan plant grows occasionally with its roots attached to other trees, and long after, the roots reach the soil. We see often on palmyra trunks seedlings of Banyan growing **epiphytically,** for a time and then, the roots encircle the stem and gradually grow downwards and get into the soil.



Fg. 32. Modified roots (left)—Monili form roots ; (right)—tubercular roots.

Adventitious roots spring from the nodes of such climbers as the Pepper, the Betel-vine and *Pothos scandens* and these are aerial and serve to attach the stem of these plants to supports (Fig. 24).

There are a host of plants, mostly of the family **Orchideae,** in which the roots hang freely in the air and never penetrate the

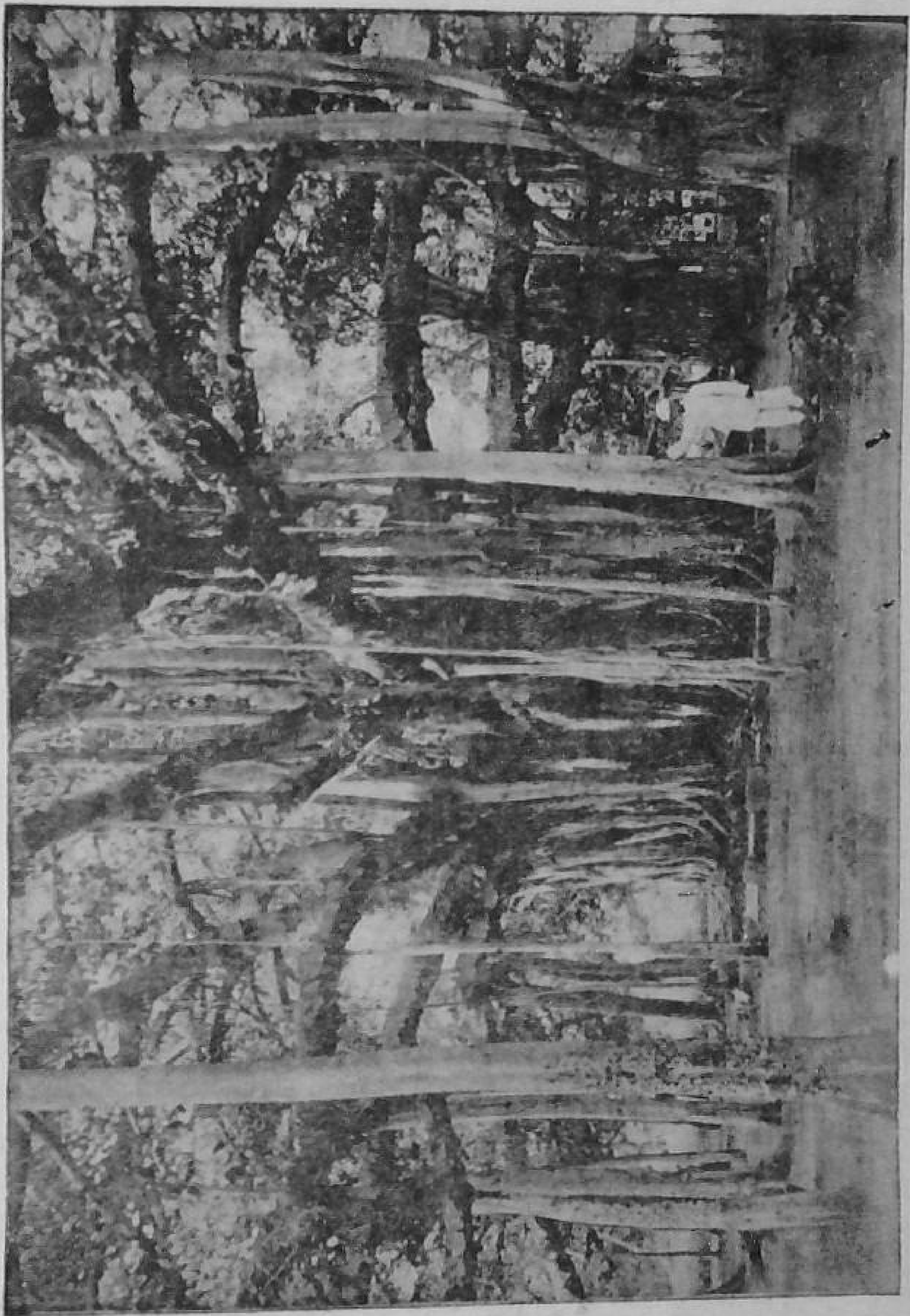


Fig. 33. Banyan tree with prop roots.

soil. The roots of the orchids *Vanda Roxburghii* and *Cleisostoma tenerum* hang freely in the air and they never get into the soil. Plants whose roots thus hang freely in the air without getting into the soil are called **epiphytes.** The roots of epiphytes are specially adapted to obtain water and salts mostly from the air. In the aerial roots of epiphytes a few of the peripheral layers of the cortex become modified into a kind of tissue, called the **velamen.** Velamen cells are dead, possess very minute pores in their walls through which air and moisture diffuse in. The cortical cells of Velamen roots have chloroplasts and the roots functionlike green leaves.

Plants growing in salt marshes have their roots in the mire, where the roots cannot obtain sufficient quantities of oxygen for

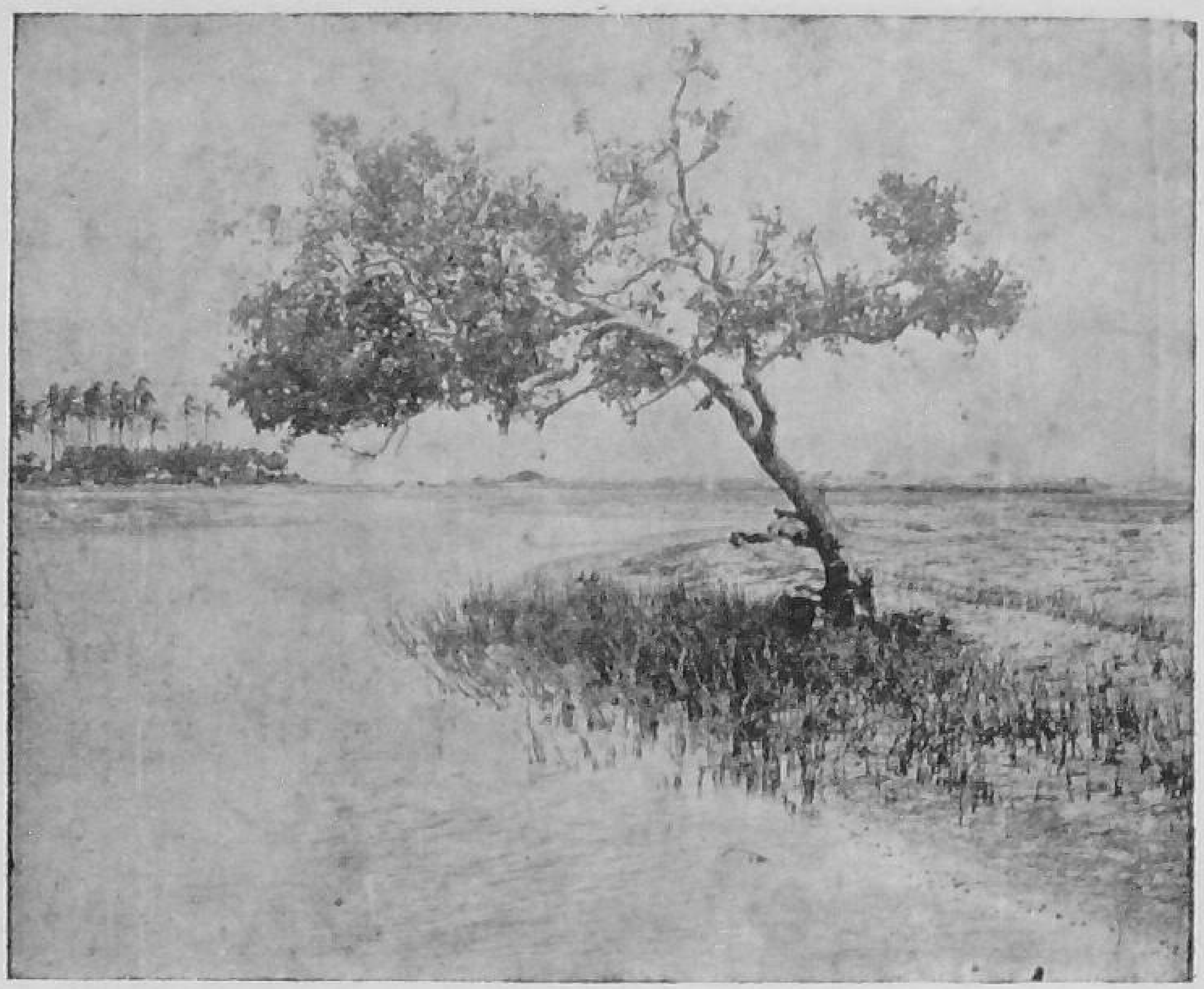


Fig. 34. *Avicennia* tree with pneumato phores.

respiration. So the roots of these plants send up into the air vertically upwards special roots, called **pneumatophores**, possessing

Fig. 35. A normal root of *Avicennia* with pneumato phores springing from it.

pores all over to allow air to get into the root-system. The mangrove trees *Avicennia officinalis* and *Sonneratia* produce these

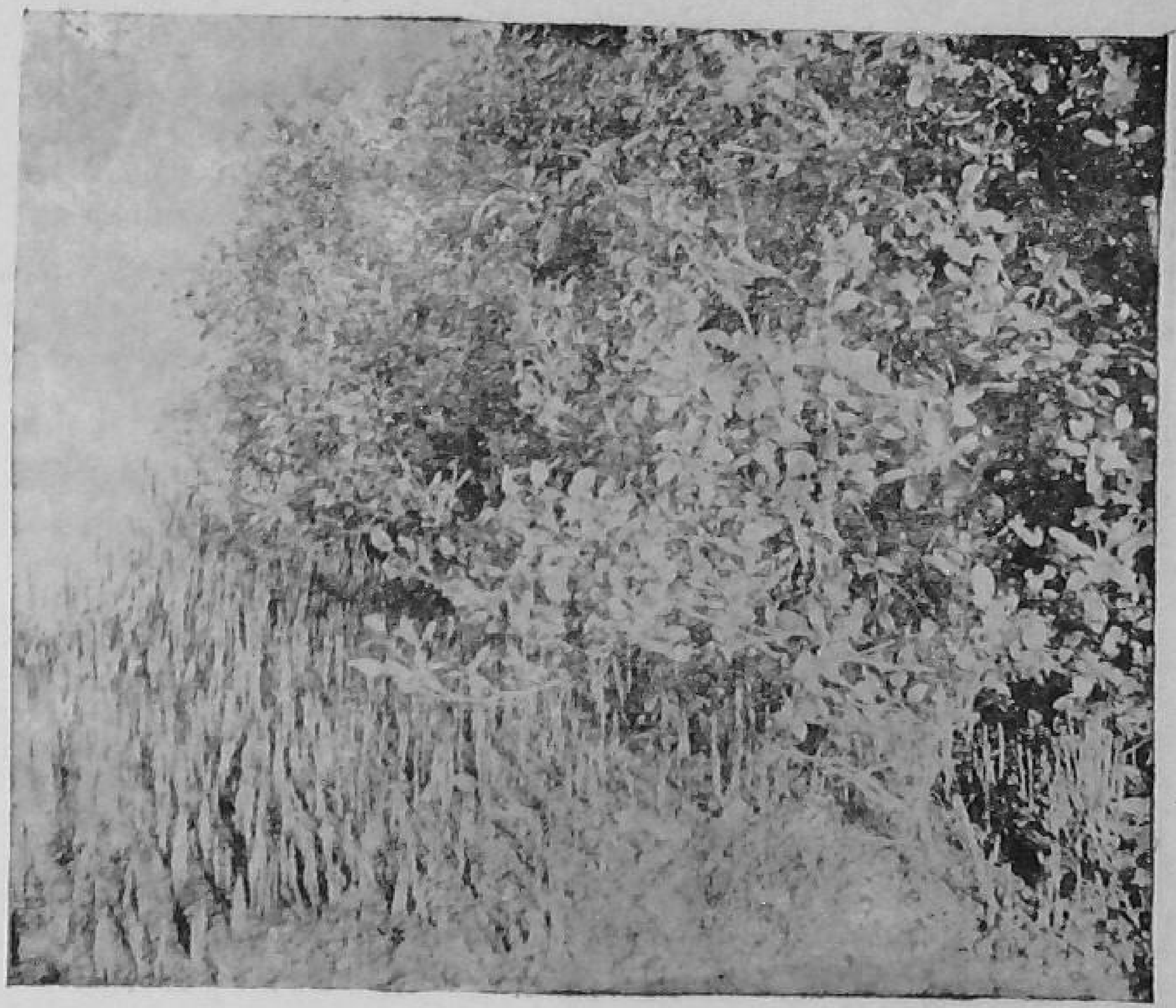


Fig. 36. Pneumatophores of *Avicennia*.

pneumatophores in abundance. (Figs. 26, 34, 35 & 36). The aquatic plant *Jussieua* and marsh plant *Sesbania aculeata* also possess peculiar roots serving as respiratory roots. The tips of these respiratory roots come up to the surface of water.

Roots are not at all green in colour, and yet this is not without an exception. In the very rare orchid *Taeniophyllum* growing on the branches of trees in dense sholas on the Kodaikanal hills, the cormus of the plant consists of only the roots and the inflorescence. (Fig. 37). Consequently the roots are all green and do the photosynthetic work. These are known as **Assimilating roots.**

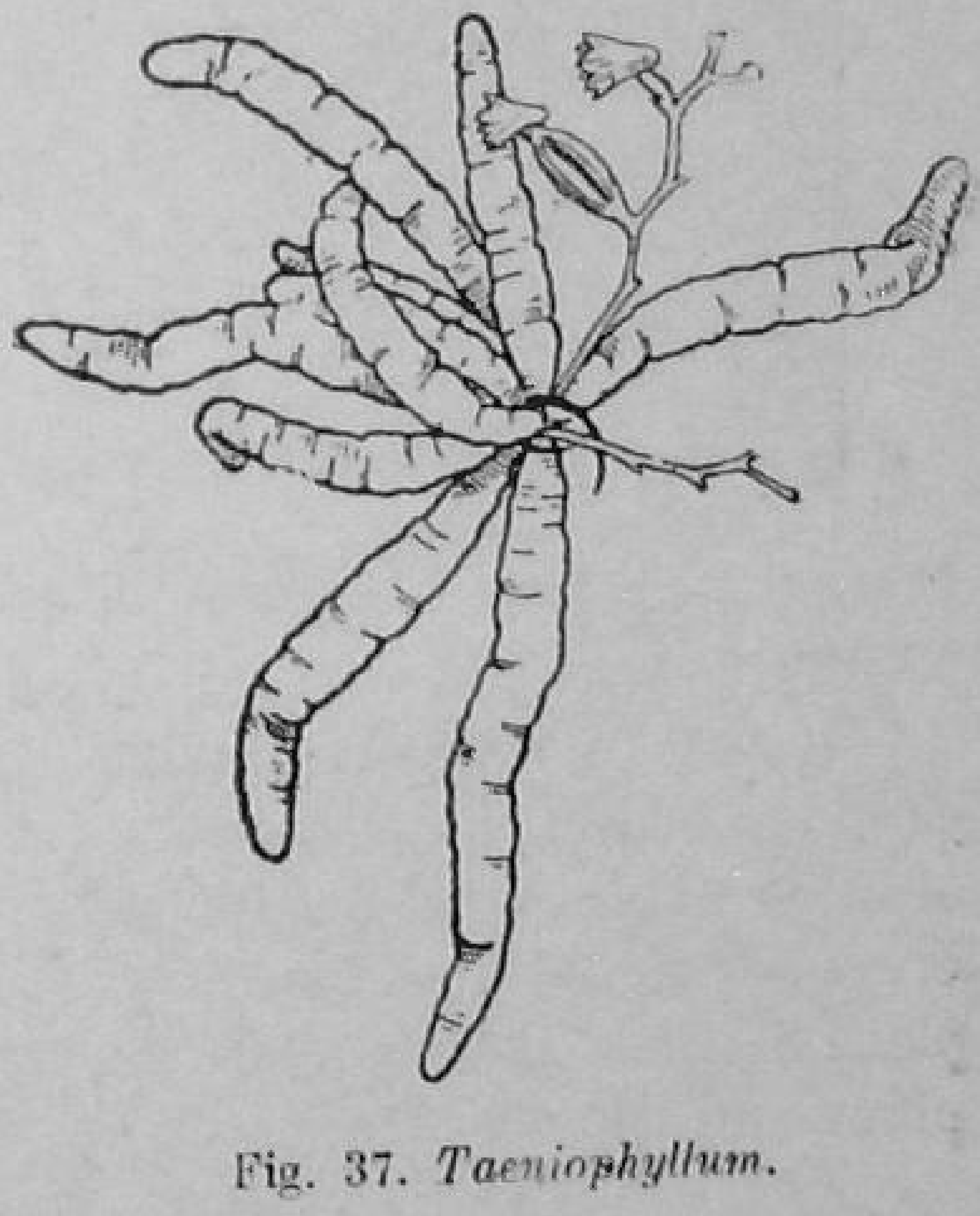


Fig. 37. *Taeniophyllum*.

Fig. 38. *Viscum* as a Parasite on *Pongamia*.

Roots of parasitic plants become modified. The phanerogamic parasitic plants *Loranthus* and *Viscum* grow on the branches of other plants, sending their modified roots into the interior of the branches of the host plants. (Figs. 38, 39). Complete fusion takes place between the vascular elements xylem and phloem of the host plant and those of the modified roots of the parasitic plant. The

modified roots of the parasitic plants are called **haustoria or 'Suckers'**. Some parasitic plants such as *Striga*, *Balanophora*

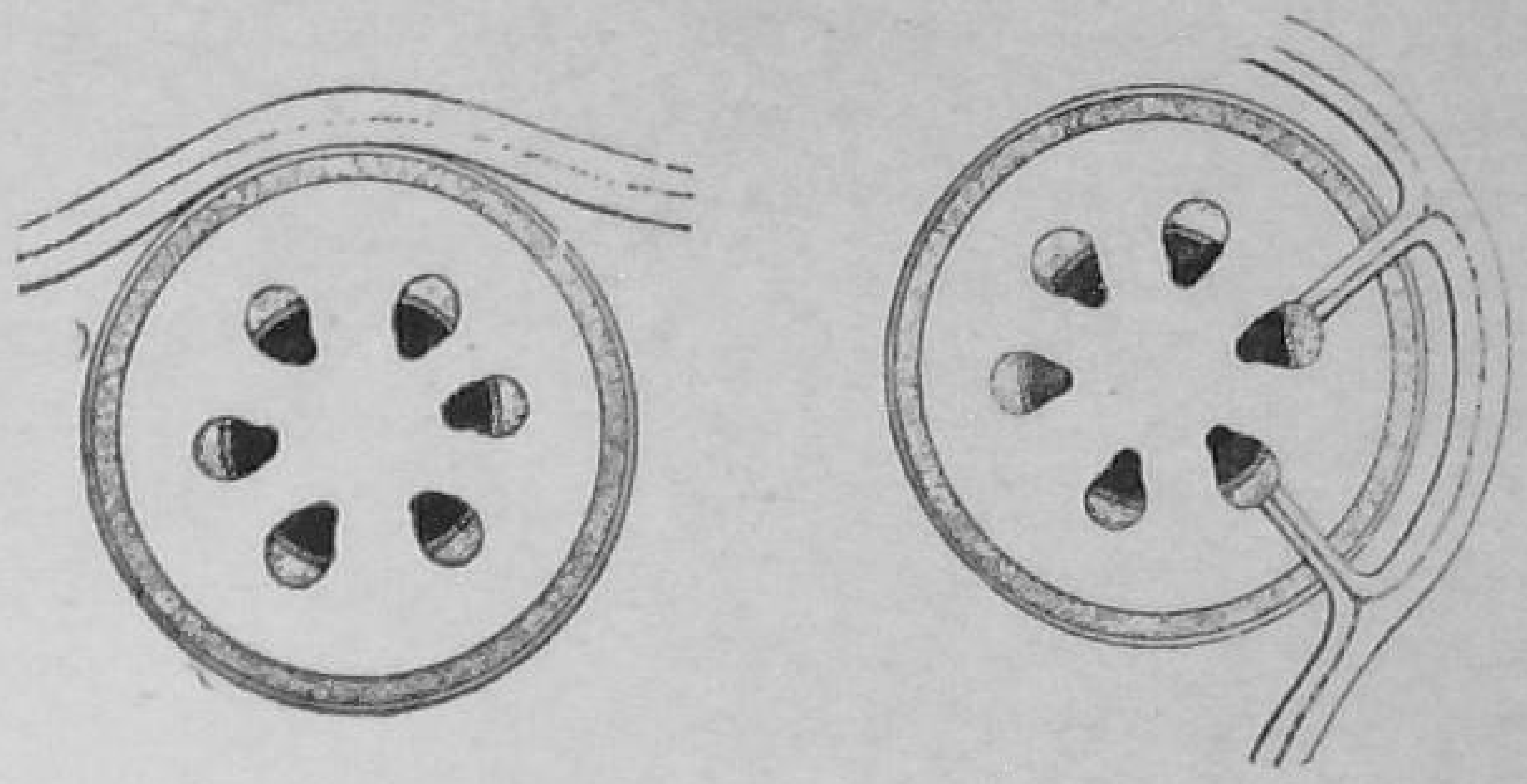


Fig. 39. Diagrammatic sketch to bring out the attachment of epiphyte (left) and parasite (right) to the host.

(Fig. 40) *Orobanche* and *Santalum* attach themselves to the roots of their host plants, instea of the stems of the shoot.

The root-systems of the plants of the family Leguminosae present certain special interesting features. We find special bodies of varying size and shape developing in the roots of these plants, and these bodies are called bacterial nodules. (Fig. 41.) They are called so, because they are brought into existence by soil bacteria. These nodules, in virtue of the presence of bacteria have the power of fixing in them the nitrogen of the atmosphere, and thus lead to an increase of nitrogen in the soil. Hence it is a practice with agriculturists **to grow leguminous plants for green manure** and also to rotate leguminous crops with other non-leguminous crops.

Fig. 40. *Balanophara* (a root parasite).

Lastly it must be noted that there are a few plants such as *Utricularia and Ceratophyllum*, in which roots do not at all develop. In these cases, the entire body of the plant made up of thin walled cells absorbs water and as such the roots are not developed.

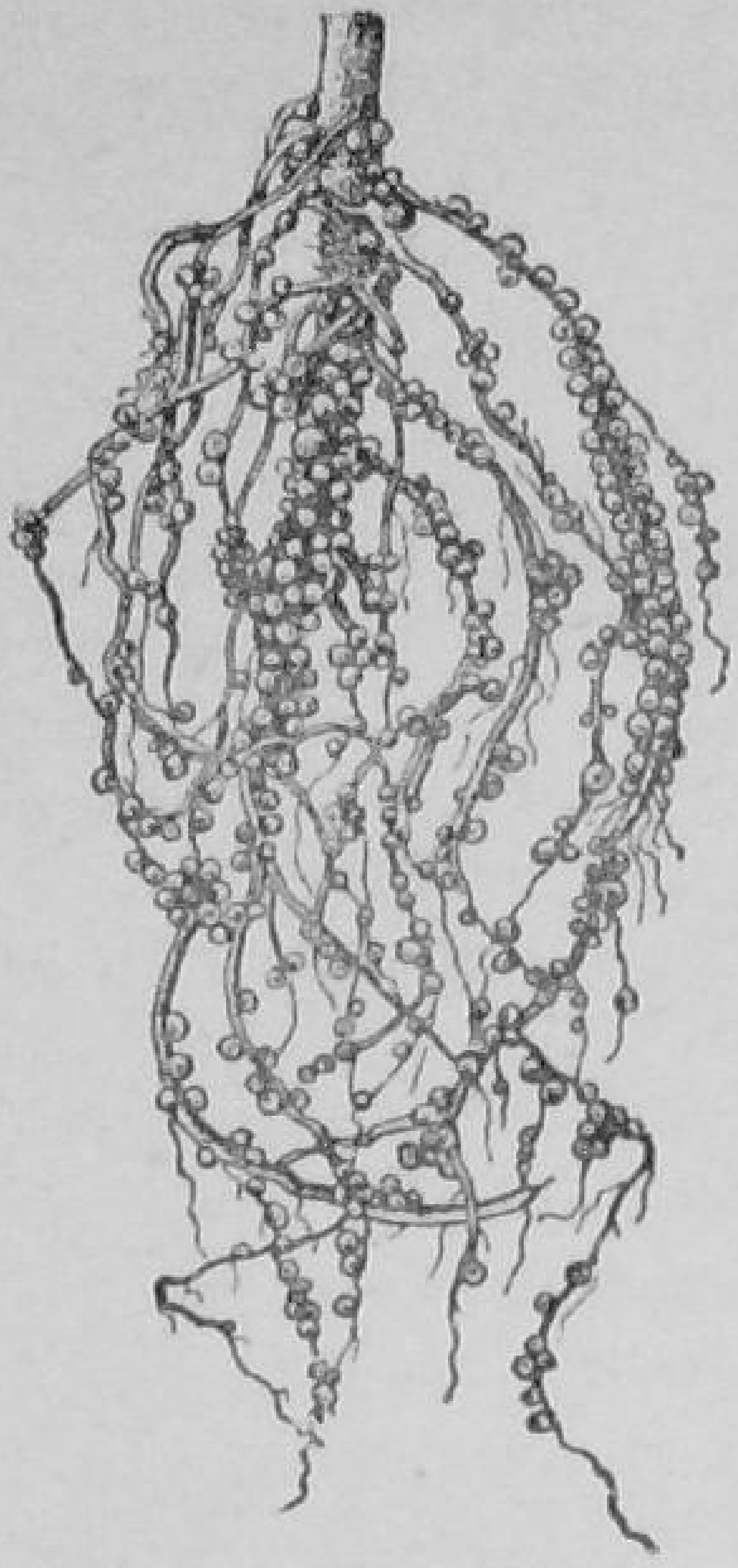


Fig. 41. Root-nodules of a leguminous plant.

Summary :—

ROOTS.

Tap-root-system.

(1) Normal in function:
e.g. *Hibiscus rosa-sinensis*, *Thespesia populnea*.

(2) Modified for storage:
e.g. Fusiform—Radish.
Napiform—Beet root.
Knol kohl.
Conical—Carrot.

(3) Modified for breathing: Pneumatophores in marsh plants:
e.g. *Avicennia*.
Rhizophora.

Adventitious root system.

(1) Prop or stilt roots:
e.g. *Pandanus*.
Banyan.

(2) Climbing roots:
e.g. *Piper nigrum* (Peper).
Piper Betle (Betel vine).
Pothos.

(3) Aerial roots—
e.g. Epiphytes like *Vanda*.

(4) Leaf roots:
e.g. *Bryophyllum*, *Begonia*.

(5) Parasitic roots:
e.g. *Cuscuta*
Cassytha.
Viscum.
Loranthus.
Orobanche.
Striga.

(6) *Floating roots* :—
e.g. *Jussieua*.

(7) Tuber: e.g. Sweet potato.

(8) Roots of all plants raised by cutting, layering and other methods of vegetative propagation.

CHAPTER V

THE SHOOT

The purpose of germination in the case of every seed is to enable the young embryo to develop into a seedling, so that it may establish itself as a plant organism, with its root-system in the soil, and its shoot system exposed to air and light. On account of the apical growth taking place at both the ends of the primary axis, the root grows downwards uniformly and persistently into the soil and the shoot grows upward straight into air and light. Therefore these regions are directly continuous one with the other at the level of the soil. The tendencies on the part of the root and the shoot, to go downward and upward respectively, are not accidental. The downward growth of the root is necessary for the well-being of the plant, because the root has work to do, which it can do best in the soil. Similarly, the upward growth of the shoot is equally essential considering that the work that it has to perform is best done, only in the air and when exposed to sunlight.

As soon as the two regions of the plant body are formed and well established in the soil, these regions though simple at first, begin to grow and become complex. The root grows vertically downward due to the growth at its apex, and along with this elongation, there arise on it lateral roots, which also in their turn possess apical growth. These lateral roots also behave exactly like the main root bearing them. Thus provision is made in every plant for mechanical support and also for the supply of water and salts from the soil. Just like the root, the shoot also is endowed with the power of continued apical growth and of forming an unlimited succession of leaves. As soon as the shoot reaches the surface of the soil, either the cotyledons spread out in the form of thin green leaves, or the first leaves of the bud of the plumule quickly unfold and place their broad surfaces more or less at right angles to the light from the sky. Leaves in the terminal bud of a seedling unfold in succession one after the other in regular **acropetal** order and, therefore, the oldest are nearest the base and the youngest close to the apex, where the immature young leaves are closely grouped so as to form a **terminal bud.** Further, in the axils of leaves, fresh buds may appear which repeat the chief characters of the terminal buds. Each bud is capable of developing into a lateral branch similar to the main shoot, and so on. The increase, taking place in the number of roots or of branches of the shoot is usually on a very prolific scale. For the utilisation of water and salts absorbed by the root-system, the increased development of branches and leaves is necessary.

The root-system and shoot-system of plants.—From what has been said above it is obvious that the root-system and shoot-system of plants are capable of indefinite growth. And, therefore, the growth and development of these parts may be continued for many years, until the plants attain very great size and high complexity in branching. Although, theoretically considered, plants are thus of unlimited growth, in nature there are actual limits imposed. We cannot expect the full development and growth of all the potential buds and parts formed in a plant. This is a physical impossibility. Of the many axillary and terminal buds appearing, some remain **dormant,** some may become modified and cease to exist while others may be damaged by fungus or insect. Seasonal variations also may arrest the growth of parts. We have also to take into account the injury caused by animals or other accidental causes. Excessive flowering sometimes leads to the shortening of the life of a plant, as is the case with annuals.

The tendency of the shoot system to become larger by the production of more branches and leaves enables it to avoid over-shadowing by other plants. Any increase in the shoot-system of the cormus of a plant means a considerable amount of demand of water from the soil. And this demand must necessarily lead to the increase of surface and branching of the root-system. To enable the root system to grow and increase in its surface, organic material must be supplied to it, and organic matter is manufactured only in the leaves. Thus we see that the development of the foliage and that of the root system are intimately related one to the other.

The branching and general shape of the head of a tree is sometimes quite characteristic of the species, as in *Odina wodier*, *Ailanthus excelsa*, *Acacia planifrons*, *Tamarindus indicus* (tamarind tree) and *Enterolobium saman* (Rain tree).

BUDS

Leaf-buds and their kinds—(i) **Terminal bud.**—The plumule is really a bud occupying the upper free end of the primary axis. We cannot make out its structure at the earlier stages of its development. But, as soon as it begins to grow, it becomes obvious that it is only a short stem hidden by a number of unfolding leaves. Gradually the stem elongates, the nodes become separated from one another, and the leaves also, which are crowded upon it at first, become separated. The shoot-system of a plant consists of a number of branches and every one of them consists of an axis and the leaves and flowers borne by it. The axis or stem is divisible into nodes and internodes, and it terminates in a bud called the **terminal bud.** All growing normal branches have buds at their free

ends. Sometimes the terminal bud is a resting bud and it is prominently seen in the twigs of mango, *Cinnamomum*, *Rhododendron* and *Mahogany*. The resting buds of *Rhododendron* are covered by small leaves called **scaly leaves.** (Fig. 42). Judging from position, the scaly leaf is really a leaf not grown fully. When conditions are favourable they grow into ordinary leaves.

Fig. 42. Scaly buds of *Rhododendron*.

(ii) **Axillary bud.**—Besides the terminal bud there are also **axillary buds** in every branch. In a branch generally there will be as many axillary buds as there are leaves. We do not usually find buds in the axils of cotyledons, although they form the first pair of leaves. But we find buds developing in the axils of cotyledons in *Arachis hypogaea* and *Cicer arietinum*. When the plumule is injured in a seedling while still young, axillary buds develop in the axils of cotyledons as in Mango and *Canavalia* seedlings.

(iii) **Accessory buds.**—In the vast majority of plants, as a rule, only one bud develops in the axil of a leaf. There are, however, a few plants in which buds appear in addition to the single axillary bud. These buds may be **collateral** or side by side, as in some Malvaceae and Liliaceae or **serial** or one above another as in *Lonicera*. Such buds are called **accessory buds.**

(iv) **Adventitious bud.**—As already stated, buds normally grow in the axils of leaves in acropetal order. Occasionally, however, buds arise from other parts of the stem or from roots or even from leaves in any order. Such buds are called **adventitious buds.** Buds appear from the cut ends of roots and this has already been referred to (see page 42). When a leaf of *Bryophyllum* is placed in a moist place or simply allowed to lie in the ground a large number of adventitous buds arise from the margin of this leaf. (Fig. 25). Shoots of *Begonia* and their leaves, when injured, produce adventitious buds.

Growing point.

A bud, terminal or axillary, is only an undeveloped compact young branch consisting of a short stem overlapped by crowded immature leaves. It is really the young incompletely developed end of a shoot (Fig. 43). The axis of the bud terminates in a free end called the **growing point**, which is a

mass of embryonic cells covered by the immature tender leaves. The leaves arising as protuberances from the surface of the growing point grow earlier and faster than the axis so that it may have protection. Though a branch has a large number of buds, all do not grow equally well. There are generally more buds than there is need for and so there will be a struggle for existence amongst them. Those buds that have more sunlight and room than the others grow best. The terminal buds and the axillary buds towards the top of the branch grow better and become larger, because they get more sunlight, air and room.

Fig. 43. A bud in development.

The result of growth may easily be studied on the twigs and branches of trees, especially in the twigs bearing scaly buds. For example, on the *Mango* or *Mahogany* tree, each twig is terminated by a bud composed of external bud scales, which enclose the closely folded foliage leaves awaiting expansion in the succeeding season. Below the terminal buds are seen leaves first and then leaf scars on the stem. Immediately above each leaf or leaf scar an axillary bud may exist which is capable of developing into a new branch; but frequently most of these axillary buds remain dormant. Lower down in the woody twig is seen a region marked transversely by many narrow scars, all lying close together. This zone may be taken as the lower limit of the growth of the preceding year, and the scars are those left by the fall of the bud scales. All the portion of the twig lying above the zone of the narrow scars is the result of the growth of one season or a year. If we examine the branch lower down

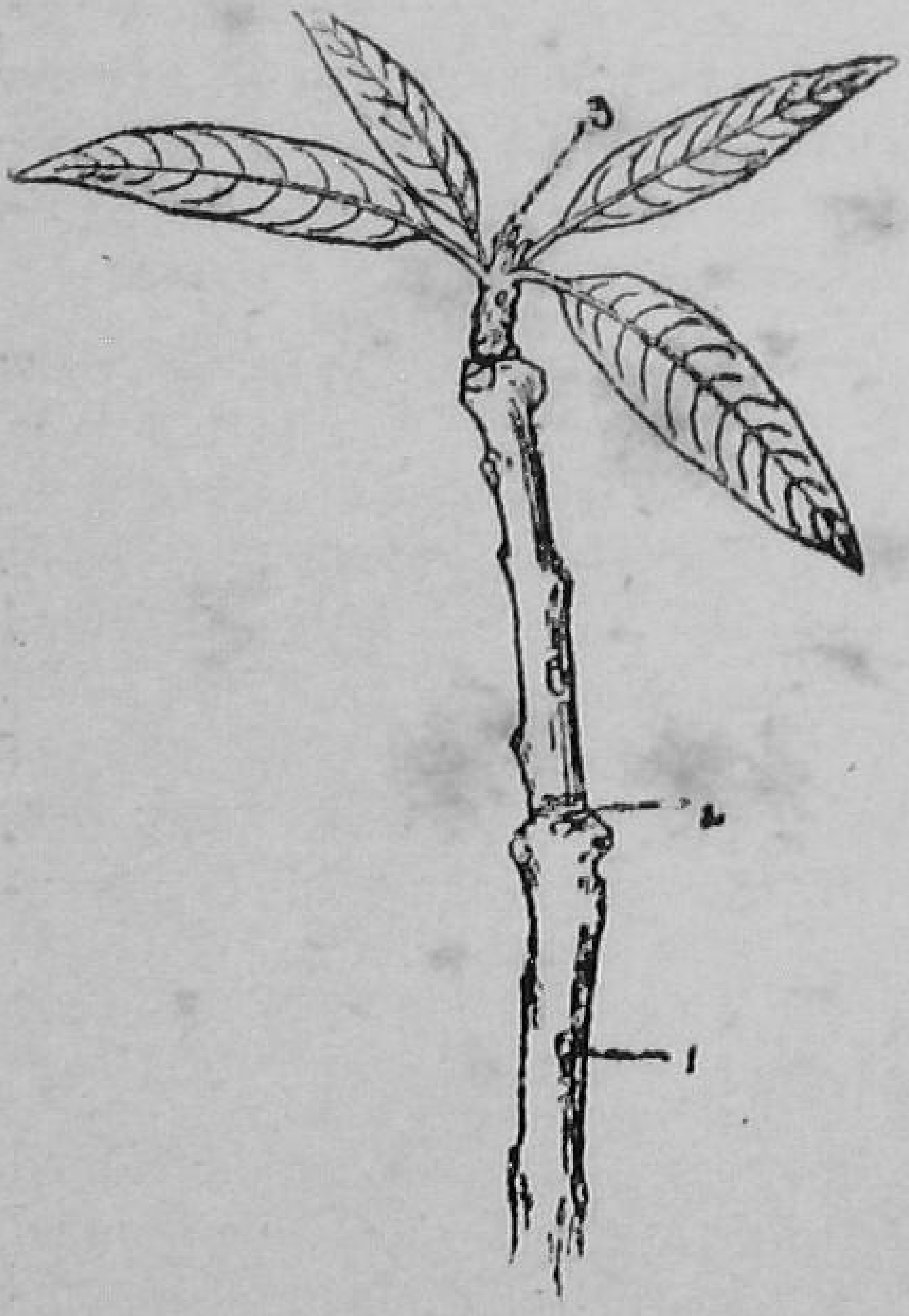


Fig. 44. A twig of Mango. (1) leaf scar ; (2) Scars of scale leaves ; (3) Scale-bud.

BUDS.

Terminal.	Axillary.	Accessory.	Adventitious.
e.g. At the growing tips of all plants.	*e.g.* in the axil of every leaf.	(1) Side by side *e.g.* in *Abutilon indicum.* (2) one above another *e.g.* *Lonicera.*	(1) From roots e.g. *Ipomoea batatas* (Sweet potato). *Millingtonia hortensis* (Indian cork tree). Cut ends of roots in *Azadirachta indica* (Neem). *Enterolobium saman* (Rain tree). (2) From leaves *Bryophyllum.* *Begonia.* *Kalanchoe.* (3) From cut end of stems or wounds—*Begonia.* (4) At the graft union in *Lycopersicum esculentum* (Tomato); *Mangifera indica* (Mango).

we shall find several zones of scars of bud scales, the record of growth. Thus, passing from below upwards along the twig we can make out its annual history, till we arrive finally at the terminal bud, which is providing for the development of the shoot for the next year. (Fig. 44).

Stems

General features

Generally shoot grows upward into the air towards light, and only in some cases it is underground. The aerial shoot is green except in total parasites. The shoots of higher plants are prominent and bear characteristic leaves, flowers, fruits and seeds. They may also bear appendages which are outgrowths on the stem.

The shoot consists of a **central axis or stem.** The axis at its **apex** terminates in the **terminal bud.** At intervals, the stem shows bulging and from these points leaves arise. These points are termed **nodes.** The intervals between two successive nodes is termed **internode.** Depending upon the species, one or more leaves arise from each node. At each node, in the angle formed by the leaf with its main axis, i.e., in the axil of the leaf, there is a bud. When the bud develops, it forms the **branch** and this branch repeats the features of the main stem.

The stem has its characteristic size and shape. It may be strong and **erect** or weak and **trailing.** When trailing, it may be,

(1) **Prostrate** or **procumbent** as in *Tribulus terrestris*,

(2) **Decumbent** when leaves and branches try to become erect as in grasses,

(3) **Creeping** as in *Centella asiatica*,

(4) **Climbing** as in *cucurbita* and *Vitis vinifera*,

(5) **Twining** as in *Dolichos Lablab.*

The stems may be (1) **round** as in cottons; (2) **oval** as in ragi, (3) **ribbed** as in gourds ; (4) **angular** as in *Cissus quadrangularis* or *Euphorbia antiquorum ;* (5) **Flat** as in *Opuntia* (Prickly pear).

The stems may bear superficial appendages. It is then described as (1) **pubescent** when short soft hairs are present ; if there are no hairs it is described as **glabrous** (ii) **stellate** hairy when the hairs radiate like stars (iii) **tomentose** when the hairs are brownish white and form a dense covering (iv) **glandular** when the hairs bear glands (iv) **prickly** when they bear stiff protuberances as in rose.

Depending upon the nature of the stem in regard to size and duration, the plants are grouped as **herbs, shrubs** and **trees.**

Herbs are small plants with soft stem. Herbs may be **annuals**, **biennials** or **perennials** depending upon the life duration of the plants.

Shrubs are woody stemmed plants of medium size. They are intermediate in size between herbs and trees. e.g., *Hibiscus rosa-sinensis* (shoe-flower).

Trees are large plants such as Mango, Eucalyptus or *Ficus benghalensis* (Banyan).

Types of branching

Monopodial branching.—Although the primary shoot of a plant continues to grow and produce many branches, in some plants it may grow as a simple straight stem without any branches and remain so throughout its life. In the case of several palms such as the coconut, arecanut, date and palmyra palms, the stem is single and no axillary branches are developed.

When a stem goes on elongating by the growth of its terminal bud for a long time, it is said to be a branch with indefinite growth. Sooner or later branches grow out from the lower axils also and these may be numerous, and all smaller than the main stem. This mode of branching of the stem is called **racemose**, and the branch whose elongation is due to the growth of the growing point of the terminal bud is said to be a **monopodial** branch.

Fig. 45. Branch of *Carissa carandas*.

Sympodial branching.—In some plants very often the terminal bud, instead of continuing the growth of the axis ends in spines or flowers. So the main axis ceases to elongate. Further elongation is carried on by the development of axillary buds. This mode

of branching is called **cymose.** In the plaint *Carissa carandas* the growing point after producing a few nodes and leaves ends in two spines, and the two axillary buds in the axils of the leaves immediately below the spines grow into branches. (Fig. 45). These also, after producing two or three pairs of leaves, end in spines and behave in the same manner. This mode of branching is termed **dichotomous** branching of cymose character.

A close examination of the flowering branch of a cotton plant and a bit of the stem of *Cissus quadrangularis* possessing tendrils at the nodes would reveal the fact, that the flowers and tendrils are opposite the leaves. In the cotton plant as well as in the *Cissus* plant, the leaves are alternate and so in a branch bearing foliage leaves only, there would be nothing opposite the leaf. But in the flower-bearing branch of the cotton plant the flower is opposite the leaf, because the growing point of the main axis ends in a flower and there is no growing point to continue the growth of the same axis. The axillary bud situated immediately below the terminal growing point, now transformed into a flower, grows and continues the axis by pushing aside the flower. So the internodes

Fig. 46. **Sympodial branching in cotton (left) and *Cissus quadrangularis* (right).**

of the flower bearing branch in the cotton plant are not all derived from the same growing point and as such appears zigzag and not straight. (Fig. 46). Such branches as these are called **sympodial** branches and the branching is **cymose.** On comparing a branch

of *Cissus quadrangularis* bearing tendrils with a branch of the same plant without tendrils the nature of the tendril becomes obvious. (Fig. 46). The tendril is in the position of the main axis, and the internode is found in the place of the axillary bud. So the tendril is the terminal growing point modified, and the internode lying between the tendril and the leaf is the axillary bud of the leaf opposite the tendril. So the tendril bearing branches of *Cissus* are also sympodial.

MODIFIED STEMS

(a) Aerial.

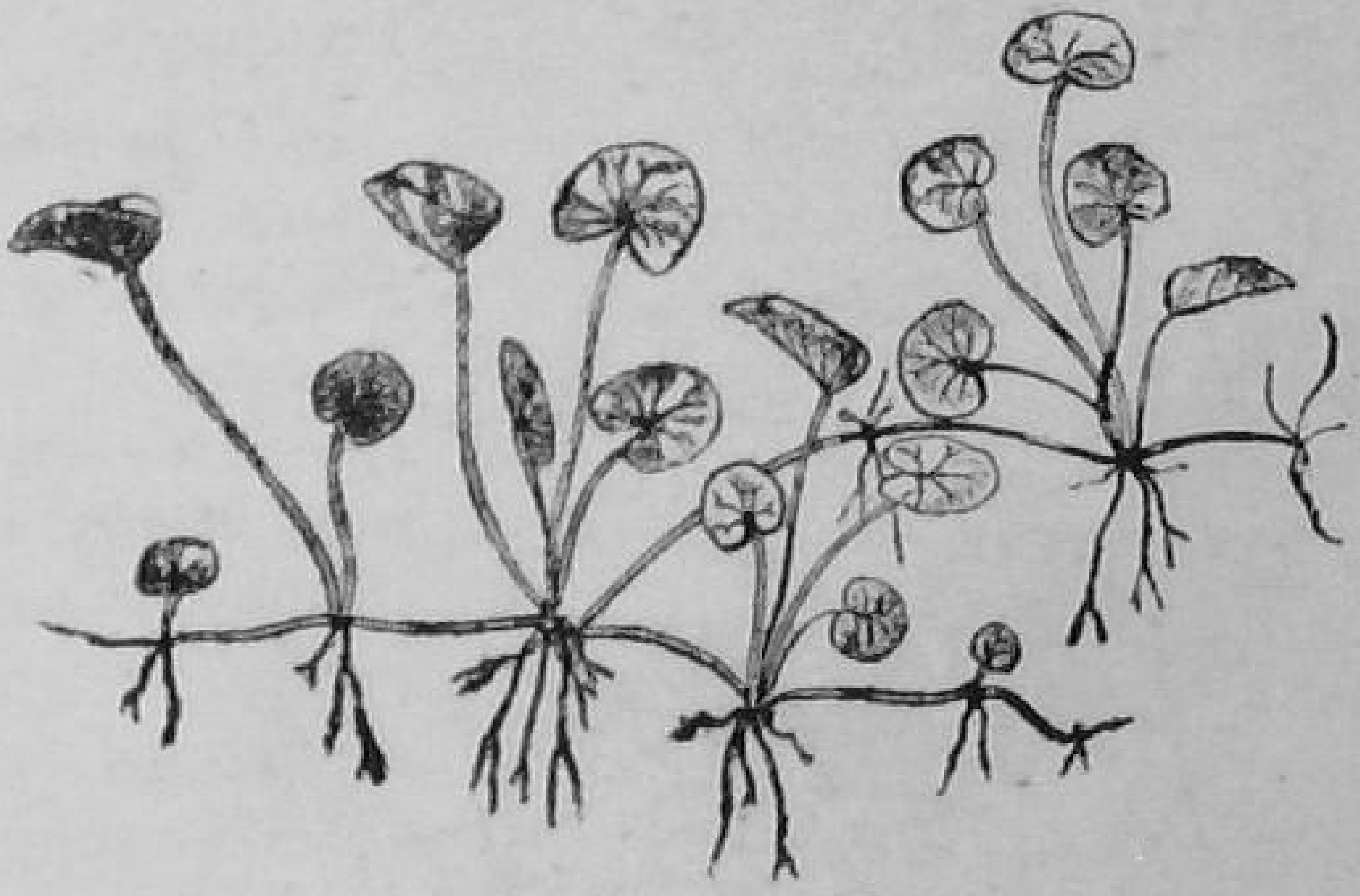


Fig. 47 Creeping stem with adventitious roots of *Centella asiatica*.

(i) **Runner.**—Most plants grow erect because the upright position of the stem is after all the most advantageous one for the plant. It is so because the stem has to bear leaves in such positions and at such distances apart, as to give them free access to sunlight and air. There are, however, plants possessing weak stems that do not maintain an erect posture. Such plants either grow on the soil creeping surface of the soil creeping along, or they get support in other ways. The plant *Centella asiatica* (Fig. 47), *Ipomoea reniformis* and *Lippia nodiflora*

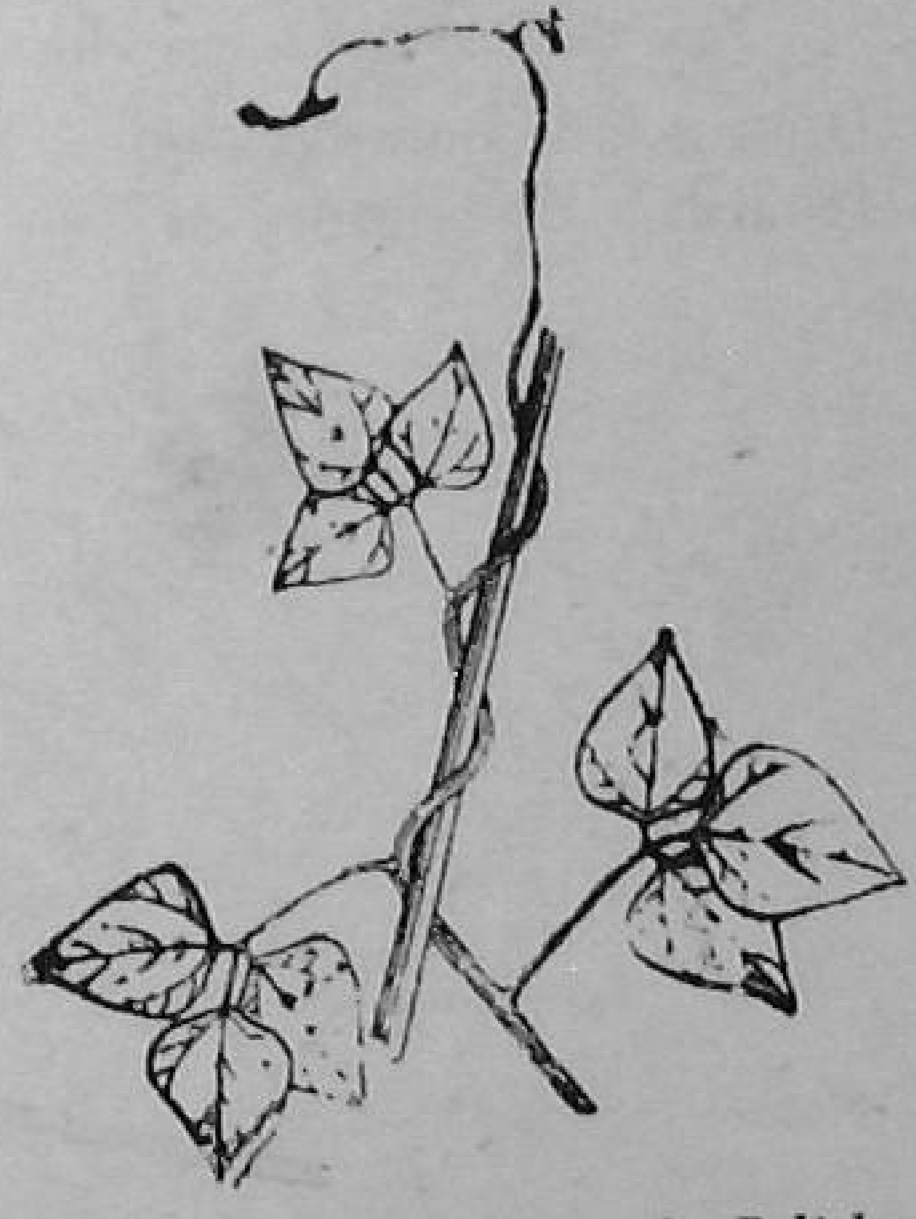


Fig. 48. Twining stem of *Dolichos Lablab.*

grow creeping along the ground. From the nodes of creeping branches adventitious roots arise, by which they get fixed to the soil. The axillary buds at nodes develop into erect foliage bearing branches. The creeping branches may become independent plants if they get severed. Such branches as these are called **runners** or **stolons.**

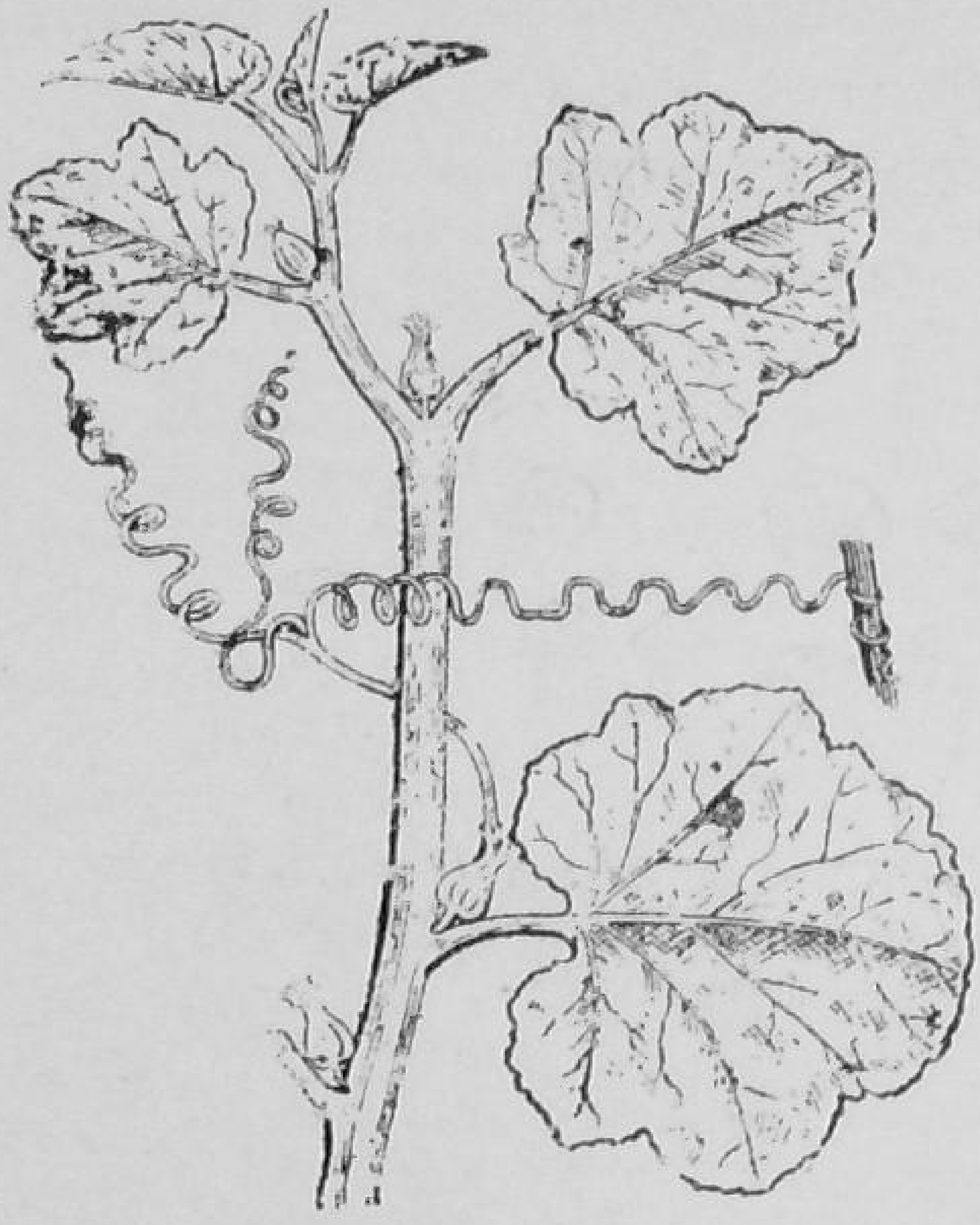


Fig. 49. *Cucurbita* stem with tendrils.

(ii) **Off-set.**—If the runner or stolon is a short one turning up to develop into a plant it is called an **offset.** eg. *Ananas sativus* or the Pine apple.

(iii) **Twiner.**—Many plants such as *Dolichos Lablab*, *Clitoria ternatea*, *Teramnus labialis* and *Ipomoea sepiaria* have weak stems that twine themselves round a support. All these plants are termed **twiners.** (Fig. 48). The support may be dead or living branches of plants growing nearby.

(iv) **Tendril.**—Certain plants like Cucumber, Gourds, and pumpkins climb by means of special structures called **tendrils.** The nature of the tendril varies with the kind of the plant. It is a branch in *Cucumis* and *Cucurbita*; (Fig. 49–54); in the Pea plant it is in the position of leaflet; it may arise from the apex of a leaf as in *Gloriosa superba*; the flower stalk sometimes develops into a tendril as in *Cardiospermum helicacabum*. In twining plants it is usually the stem that twines

Fig. 50. Tendrils of *Cardiospermum helicacabum*.

round, and the direction of the twining may be clockwise or anti-clockwise. There are a few instances in which the petiole

Fig. 51. Tendrils of a Cucurbit.

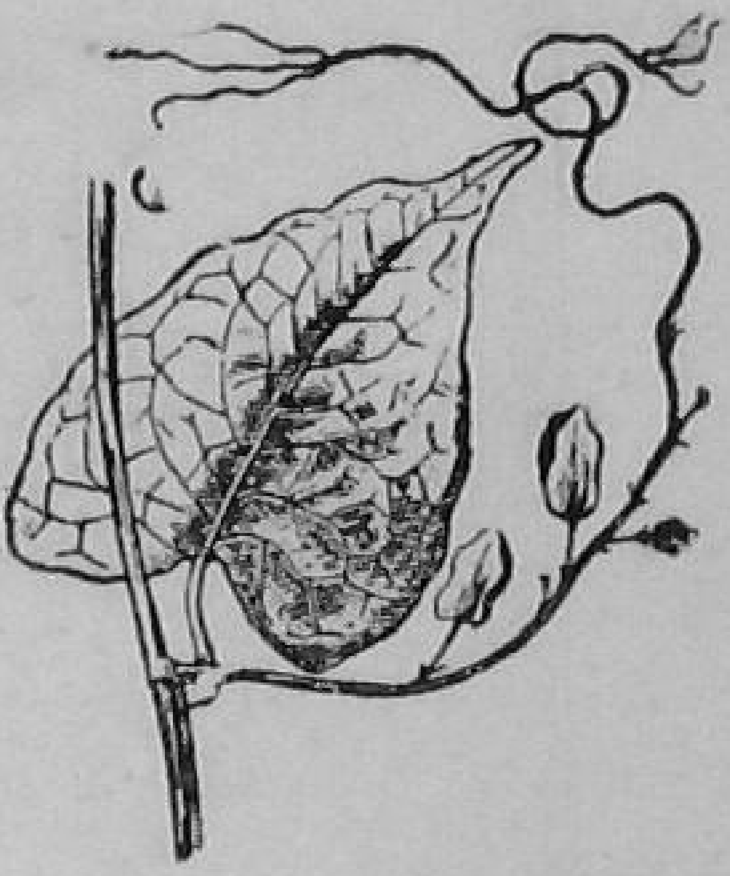


Fig. 52. Tendrils of *Antigonon*.

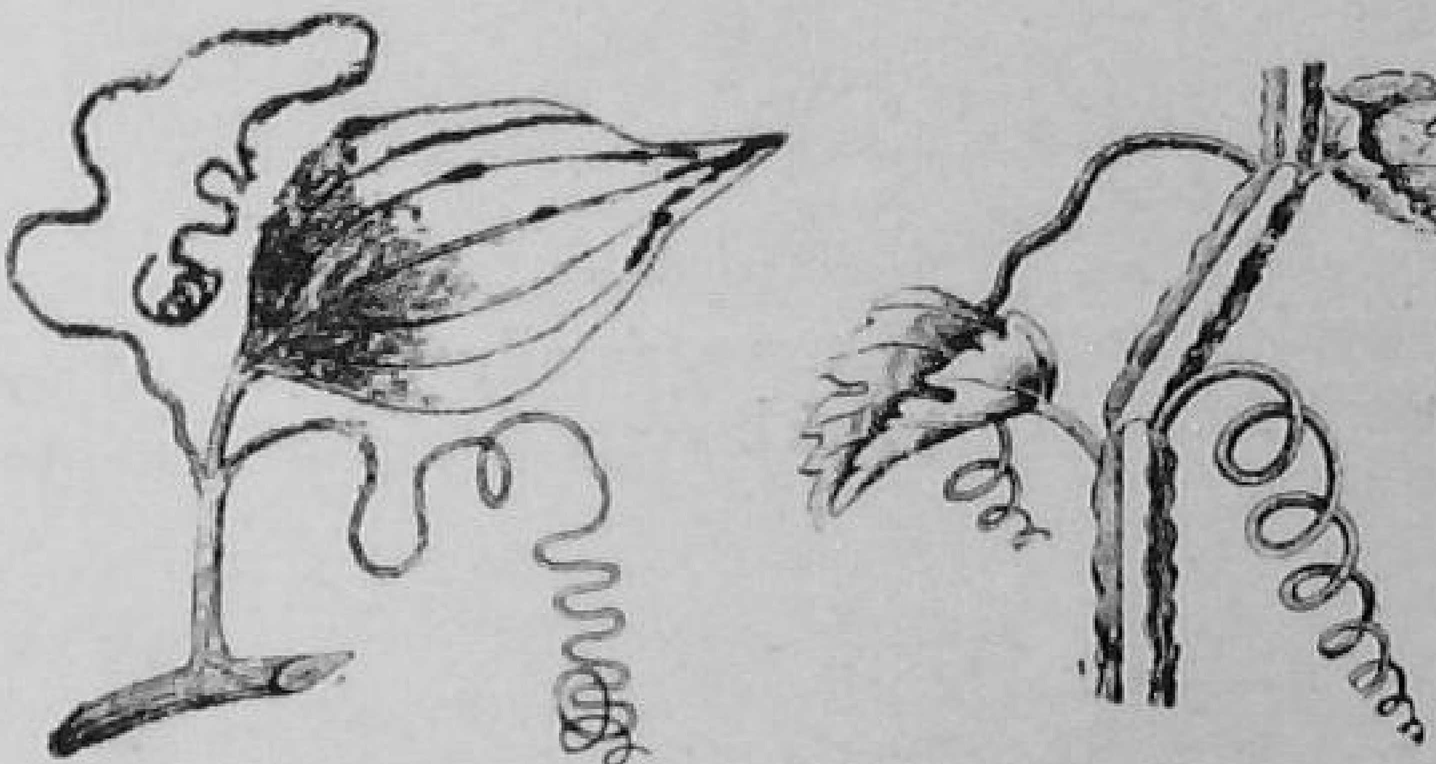


Fig. 53. Tendrils of Smilax (left) and Tendrils of *Cissus quadrangularis* (right).

twines round, as in *Clematis* and *Solanum seaforthianum*. The tendrils, as soon as they secure attachment at their tips, coil into two spirals and the point of reversal is also clearly seen. (Fig. 49).

(v) **Thorns.**—The axillary branches in some cases remain short and pointed at their tips instead of growing into ordinary leafy branches. Branches of this kind are called **spines** or **thorns.** Occasionally these spines bear leaves and may develop into leafy branches under exceptionally

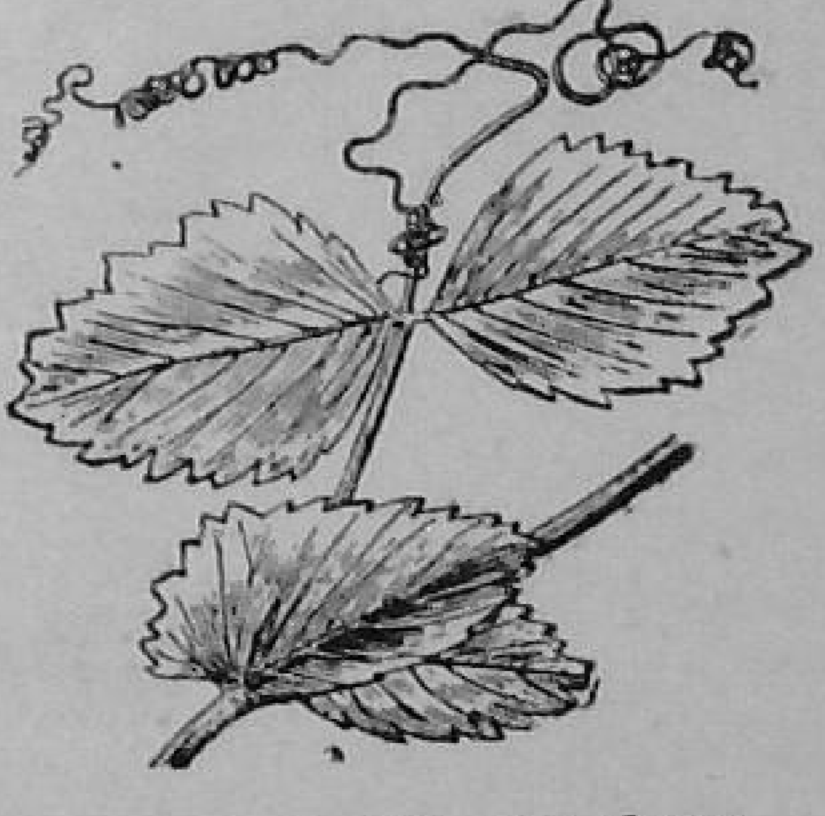
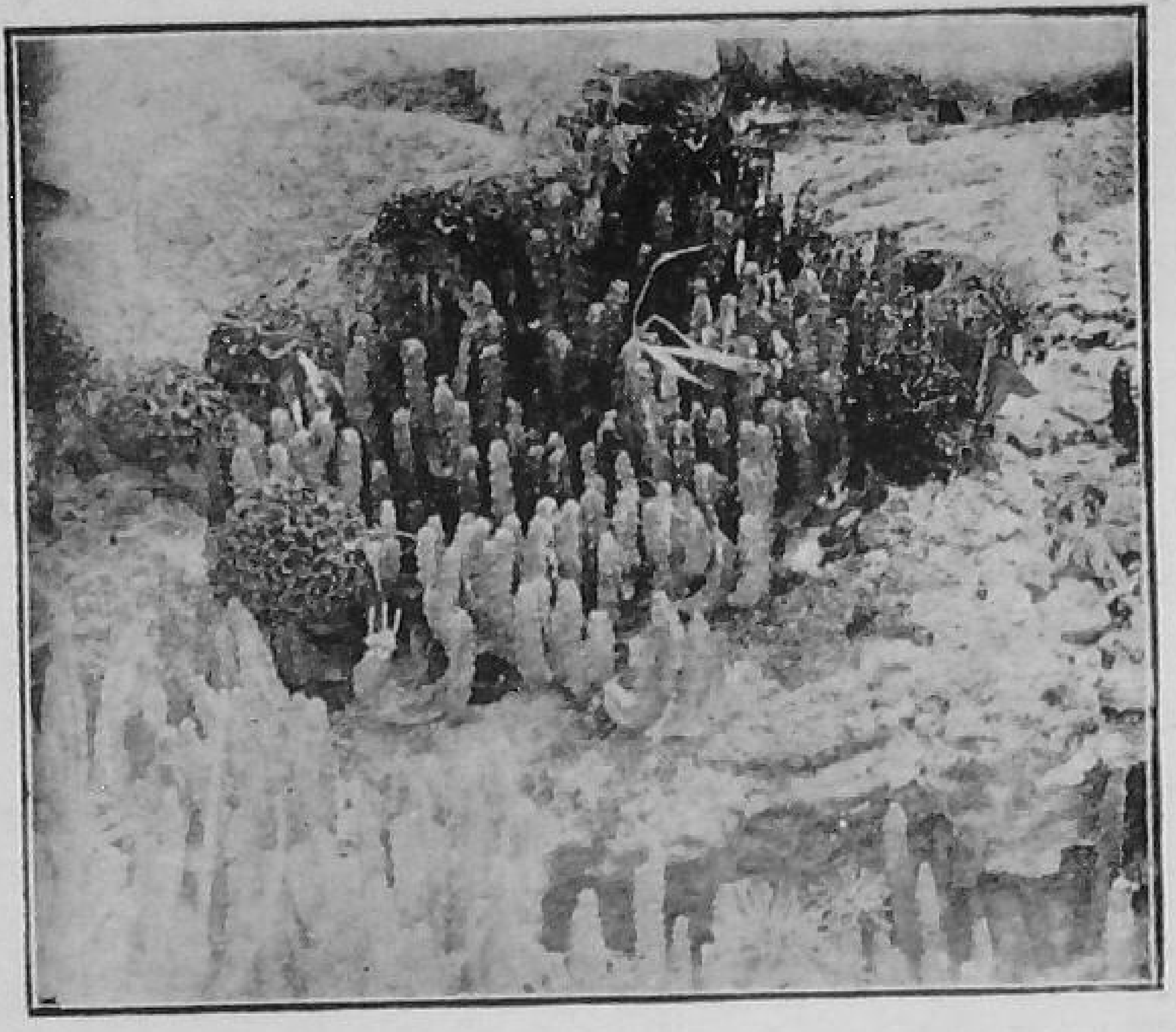


Fig. 54. Tendrils of *Lathyrus*.

favourable conditions and more so under cultivation. Spines occur in plants of the genera *Citrus*, *Gymnosporia*, and in the specie ***Scolopia*** *crenata*, *Phyllochlamys spinosa* and *CommiphoraBerryi*



Bcuorosia (cladodes).

The spines in *Citrus* plantsare generally quite naked and green. In *Commiphora Berryi* the spines become numerous and prominent,

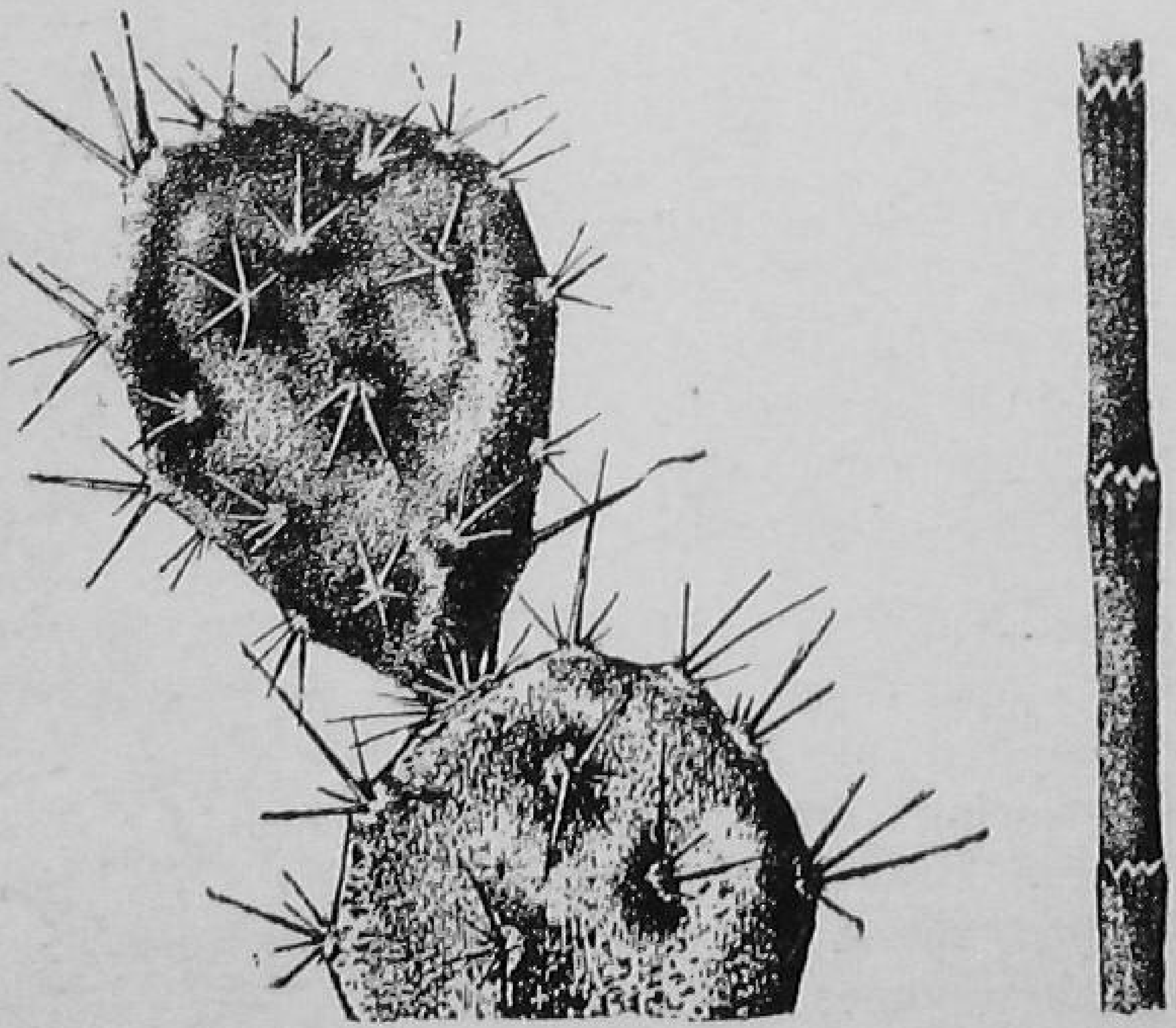


Fig. 55. Cladode *Opuntia* (left) and *Casuarina* (right).

and the leaves become fewer and scanty when growing in very dry situations.

(vi) **Cladode.**—There are many plants growing in dry situations in which the shoot system consists of stems only with out any leaves. For example, in *Casuarina*, (Fig. 55), *Opuntia*, and *Euphorbia antiquorum* leaves are not developed and the stems become fleshy and green. Such modified stems as these are termed **cladodes** or **cladophylla.**

(b) Underground

When stems grow underground they are often mistaken for roots, because they are not easy to recognise as stems. Like aerial stems, the underground stems show division into nodes and internodes. At the nodes, instead of green leaves, scales are found and in the axils of these scales axillary buds arise.

As underground stems differ from one another, some of the principal forms have for convenience been given special names. In some plants the underground branches do not materially differ from the ordinary aerial branches except in the loss of green colour and foliage leaves. For instance the underground branches in *Cynodon dactylon* (Doob grass or Hariali) are pale in colour and at the nodes whitish scales are found instead of leaves.

(i) **Rhizomes.**—The underground stems of *Curcuma longa*, *Canna indica*, *Acorus calamus* and *Pteris aquilina* grow more or less horizontally giving off leafy shoots above and roots below. The elongated forms of underground stems like these are called **root-stocks** or **rhizomes.** The stems of those mentioned above become much thickened on account of the storage of food material. In some plants like *Panicum repens* and *Cyperus rotundus* the rhizomes are partly thin and get thickened partly here and there. In rhizomes, the nodes, internodes and the axillary buds are clearly seen. Generally rhizomes do best at a certain definite depth and if this depth is changed, they will go downward until the average depth is obtained. Rhizomes ordinarily grow horizontally, maintaining their average level in the soil, because greater depth is sure to interfere with the development of aerial shoots, while extreme shallowness would mean less protection.

Rhizomes branch freely.—In some plants as in *Curcuma longa* Turmeric. (Fig. 56, 57) and ginger the whole of the shoot system may consist entirely of underground stems, producing leafy aerial branches, or only leaves may emerge as in the case of ferns. The rhizome may grow in length, the apical bud persisting and axillary buds growing out into aerial branches, or the apical bud may grow

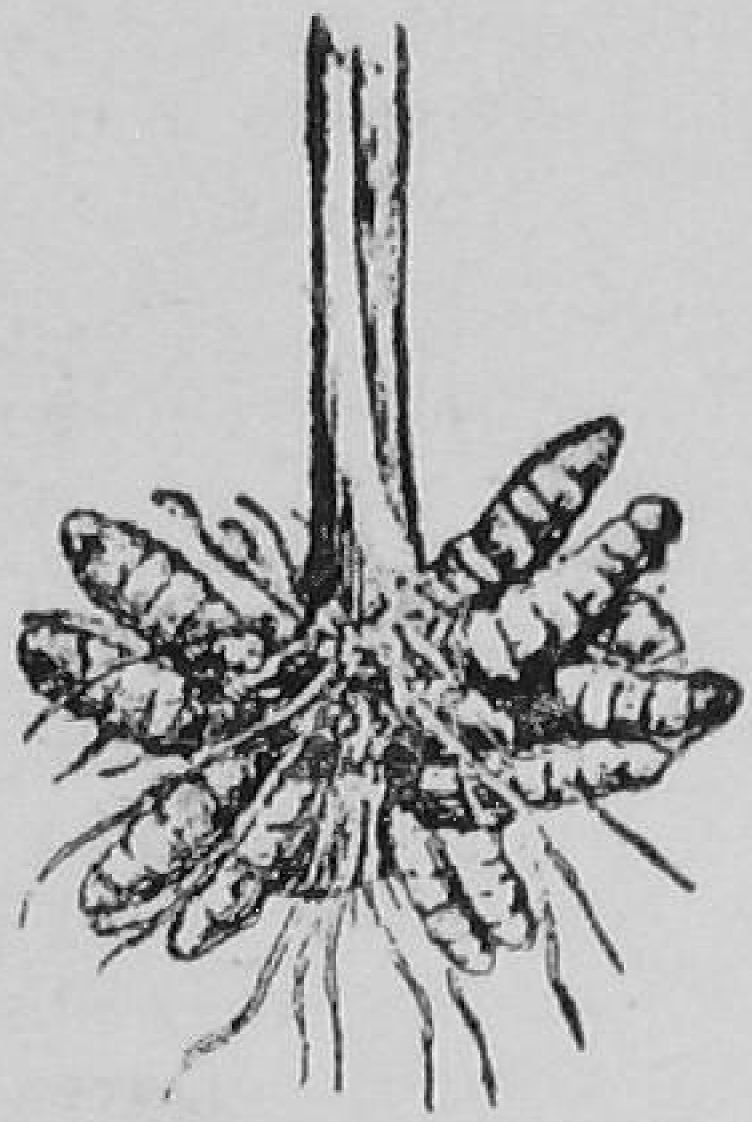


Fig. 56. Rhizomes of *Curcuma longa.*

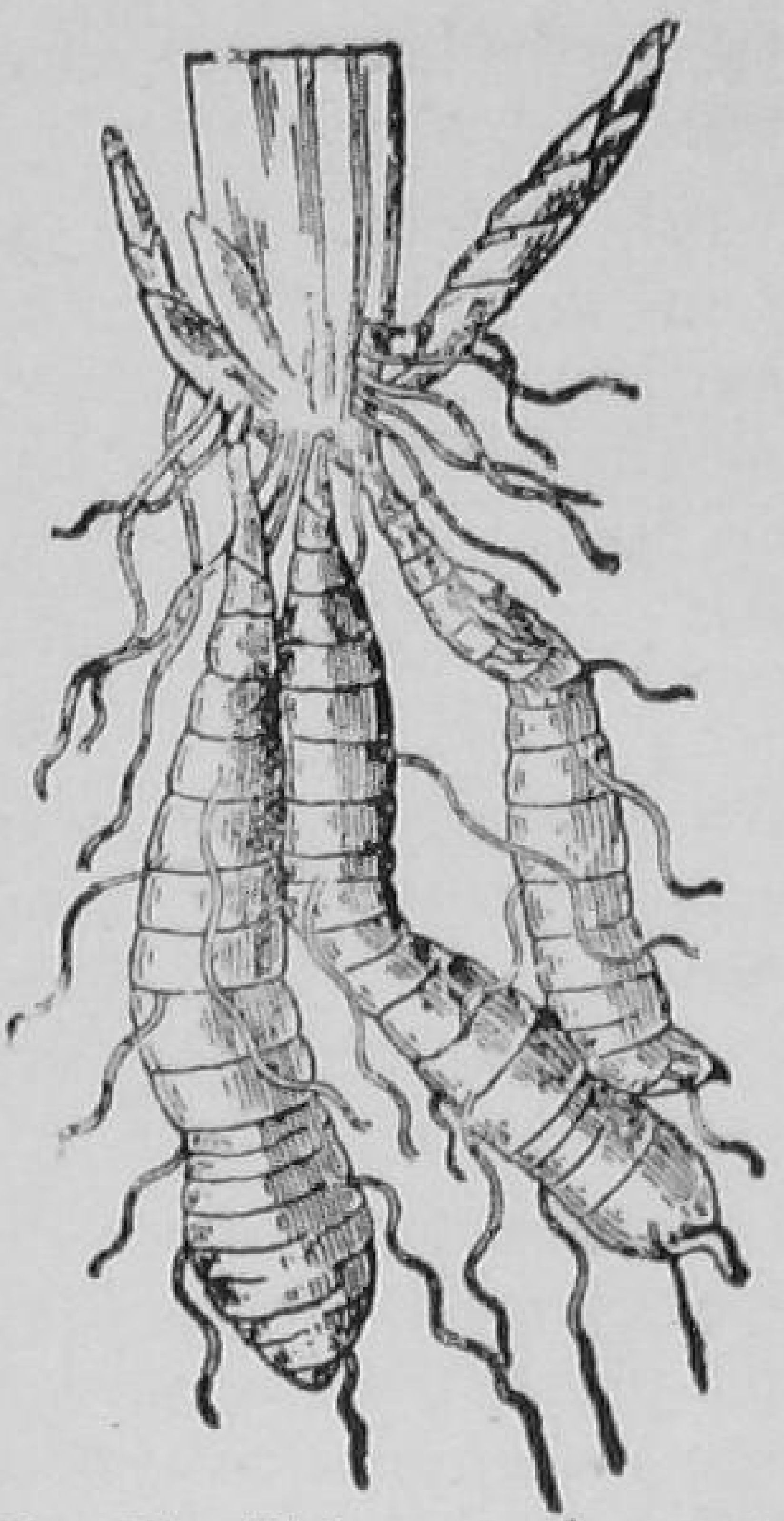


Fig. 57. Rhizomes of arrow-root.

Fig. 58. Stem tubers of Potato.

out as an aerial branch, the growth of the rhizome in length being continued by lateral buds as in *Canna.* The former is of the monopodial type and the latter is sympodial. Plants possessing rhizomes are **best adapted for invading and taking hold of the soil already occupied by other plants, because the rhizomes creep through the soil and occupy the places where seeds have absolutely no chance of spread.**

(ii) **Tubers.**—Sometimes, as in the potato plant (Fig. 58) some branches grow underground and these instead of elongating swell and become thickened **at the end of the branch** on account of

the storage of starch. Thickened branches of this sort are termed **tubers.** The potato tuber is particularly good for study. In it the buds are clearly seen as "eyes" and these are found in the axils of little scales which represent leaves. The rounded bodies found in connexion with the slender rhizomes of *Cyperus rotundus* are of the nature of tubers.

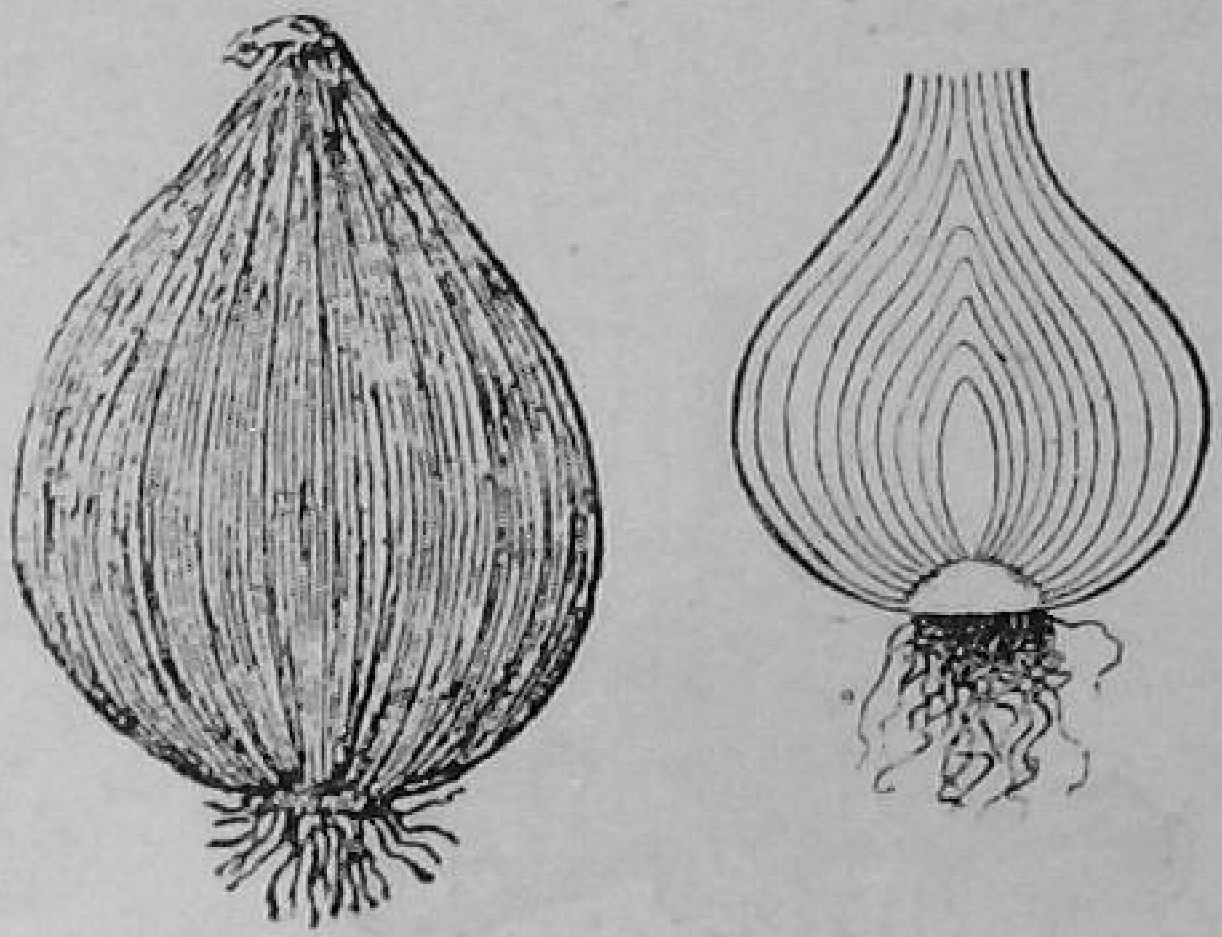


Fig. 59. Onion bulb.

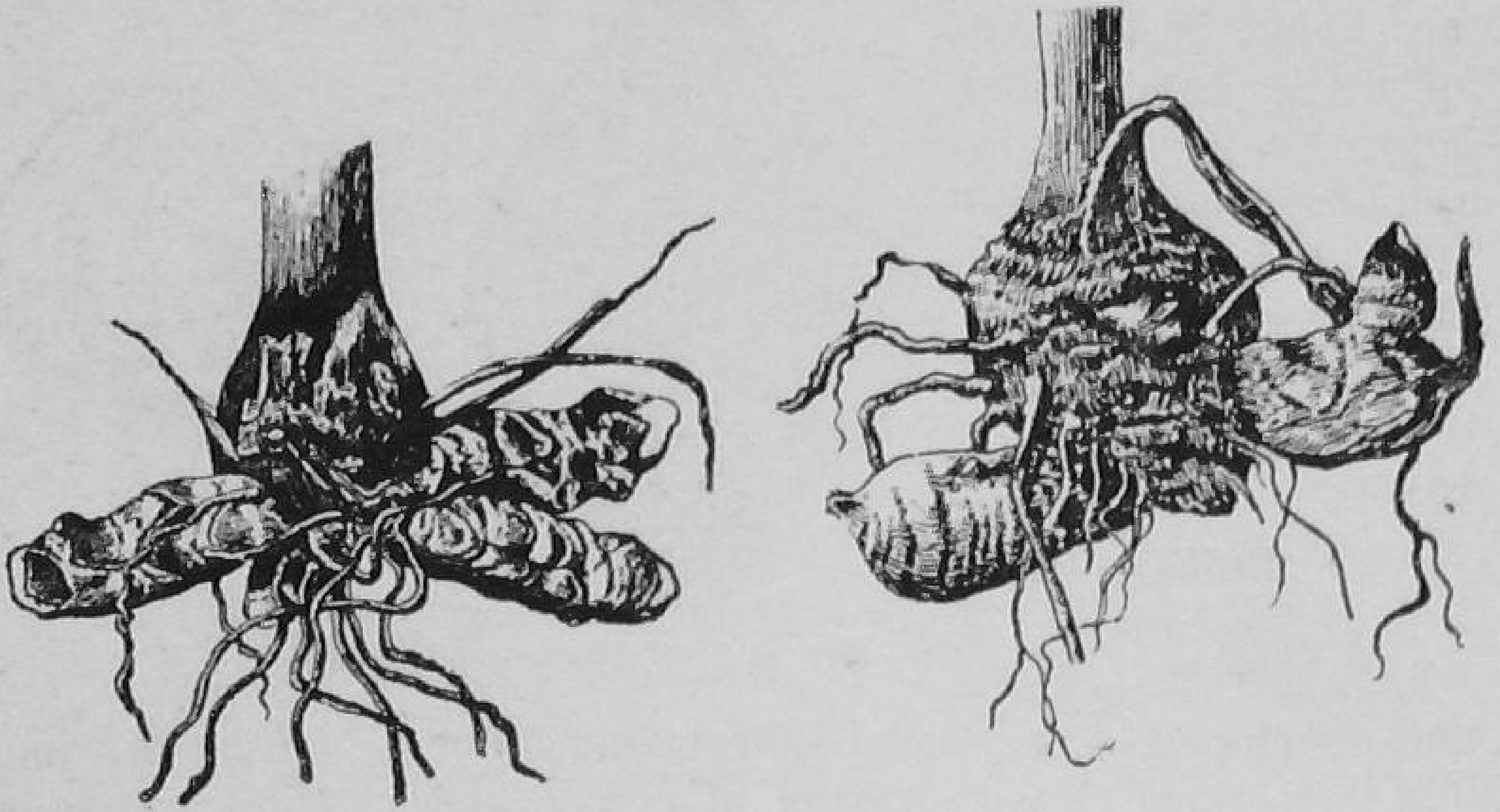
(iii) **Bulbs.**—There are a few plants in which the shoots are not developed, but much abbreviated. These consist of only disc-like stems with a covering of leaves, outer scales and inner mostly fleshy, as in the familiar plants Onion, (Figs. 59, 60) garlic, *Crinum*, *Scilla* and *Urginea*. The scales of onion are fleshy owing to storage of food in them instead of in the stem. If we cut an onion longitudinally, we find a disc-like structure bearing roots below and a number of sheathing fleshy and scale-leaves and buds above. Modified shoots such as the onion are called **bulbs**. The sedge *Cyperus bulbosus* a familiar weed bears small underground bulbs.

Fig. 60. Onion bulb.

The inner leaves of a bulb are either fleshy as in onion, or they are merely the sheathing leaf bases of ordinary foliage leaves, as in *Crinum*. The bulb in *Polyanthes tuberosa* is generally like that of *Crinum* or onion, but the axis becomes a large mass instead of remaining small and the sheathing leaf bases become very few. Externally it is like a bulb and so such ones are sometimes called "**solid bulbs**". This is really an intermediate form of stem leading to what is usually described as a **corm.**

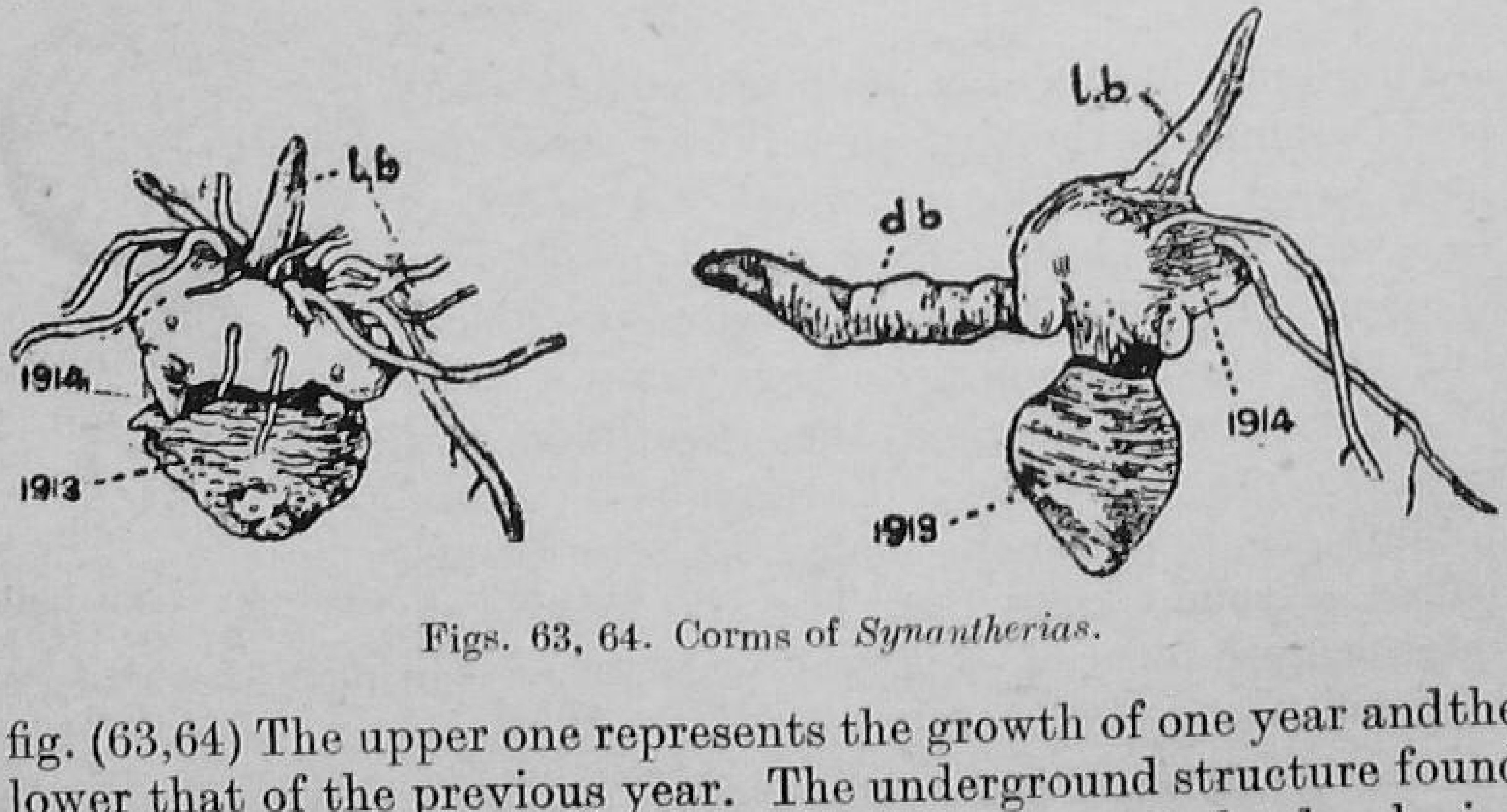
(iv) **Corms.**—The underground massive part of the plant *Amorphophallus* or *Synantherias* is the main stem modified and

this is a good example of a **corm.** (Figs. 61–64). Though this is essentially like a tuber it differs from it in being a main stem instead of a branch.



Figs. 61–62. Corms of *Colocasia*.

The corm of *Amorphophallus* or *Synantherias* bears a large bud at its depressed apex. The apical bud pushes out the leaves one at a time. In addition to this bud a number of smaller ones are found scattered all over the surface of the corm and also in the depressed part. Some of these buds may develop into **daughter corms.** Sometimes we find corms of different periods of growth remaining attached to one another. For example, the corms in *Synantherias sylvatica* usually consist of two bodies as seen in



Figs. 63, 64. Corms of *Synantherias*.

fig. (63,64) The upper one represents the growth of one year andthe lower that of the previous year. The underground structure found in *Colocasia antiquorum* in direct continuation with the developing

bud is the corm; and this usually bears branches somewhat elongated and resembling rhizomes.

Summary

STEMS.

- Aerial
  - Normal Erect
    - e.g. *Hibiscus rosasinensis.*
    - *Polyalthia longifolia*
  - Modified
    - (1) WEAK STEMMED
      - (*a*) Climbing
        - (i) by tendrils:
          - Branch in *Cucurbita*
          - Leaflet in *Pisum* (Pea)
          - Leaf apex in *Gloriosa*
          - Stipule in *Smilax*
          - Petiole in *Clematis*
          - Terminal bud in *Cissus quadrangularis*
          - Flower stalk in *Cardiospermum helicacabum*
          - Flower bud in *Antigonon*
      - (*b*) Twining
        - e.g. *Dolichos Lablab*
      - (*c*) Trailing
        - (i) Procumbent in *Tribulus terrestris*
        - (ii) Decumbent in grasses
        - (iii) Creeping in *Centello asiatica.*
    - (2) CLADODE e.g. *Opuntia, Casuarina*
    - (3) THORN—e.g. *Commiphora berryi*
- Underground. (Modified.)
  - (1) RHIZOME
    - e.g. *Curcuma longa* (Turmeric).
    - Ginger.
    - *Canna.*
  - (2) TUBER
    - e.g. Potato.
  - (3) CORM
    - e.g. *Amorphophallus* (yam)
  - (4) BULB
    - e.g. Onion
    - Garlic

CHAPTER VI

THE LEAF

Leaves are the most conspicuous lateral appendages of the stems of the shoot-system. They are of paramount importance to a plant, as they are the organs mainly concerned in the production of organic material. Although a leaf is an outgrowth of the stem like its branches, it differs much from a stem, whereas a branch does not. Leaves are always found in a plant and the most striking event in a plant, even from the seedling stage, is the rapid production of leaves. Ordinarily leaves do not persist on the stem, but fall off after some time leaving **leaf scars** on the stem. As old leaves fall off new leaves appear, so that there will be leaves always in most trees, except in deciduous trees where the leaves are shed during certain period of the year.

Besides the green foliage leaves, which alone are meant when we speak of leaves, there are other lateral outgrowths which may be brought under the term leaf. **The cotyledons, scale-leaves,** bracts, **sepals and petals are also leaves modified.** The cotyledons are really the first leaves of seedlings and we have already dealt with them in an earlier chapter. The **scale-leaves** are usually small, brown, membranous, without the green colour. Judging from their position and arrangement on the stem they are really reduced leaves. In most cases they are only leaf bases, petiole and lamina being absent. They occur on many underground stems and on scaly buds. Their function is chiefly protective. **Bracts** also, though connected with flowers, are really leaves. They vary very much in shape and size. **Sepals** and **petals** are parts of the flower and hence they are floral leaves, and they will be considered later on in connexion with the flower.

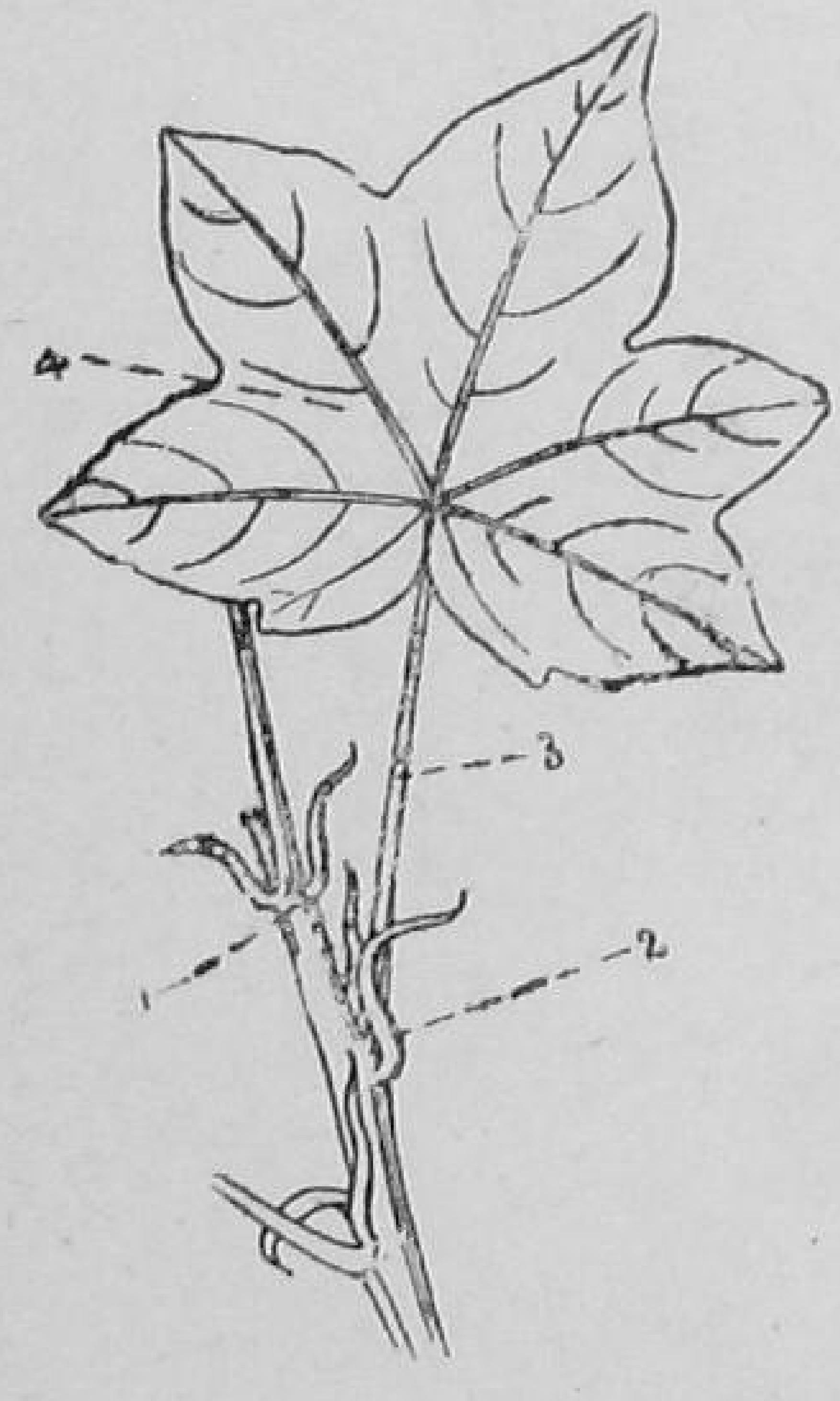


Fig. 65. Parts of a typical leaf. 1 node ; 2 stipules ; 3 petiole ; 4 blade or lamina.

Parts of a leaf.—In a typical leaf we have three distinct parts, the **leaf base** which connects the leaf with the stem, a stalk or the **petiole** and the **blade** or **lamina,** the expanded portion (Fig. 65). We do not find all these three parts in all leaves. For instance we do not find the stalk in the leaves of the plants *Lactuca runcinata*, *Argemone mexicana* and *Sonchus asper*, although the lamina is present in all these plants. The leaf blade is present in almost all plants, and similarly the basal portion of the leaf must be expected to be present in the leaves of all plants. Young leaves forming a covering in buds do not possess stalks. The stalks develop only later, with the unfolding of the leaves.

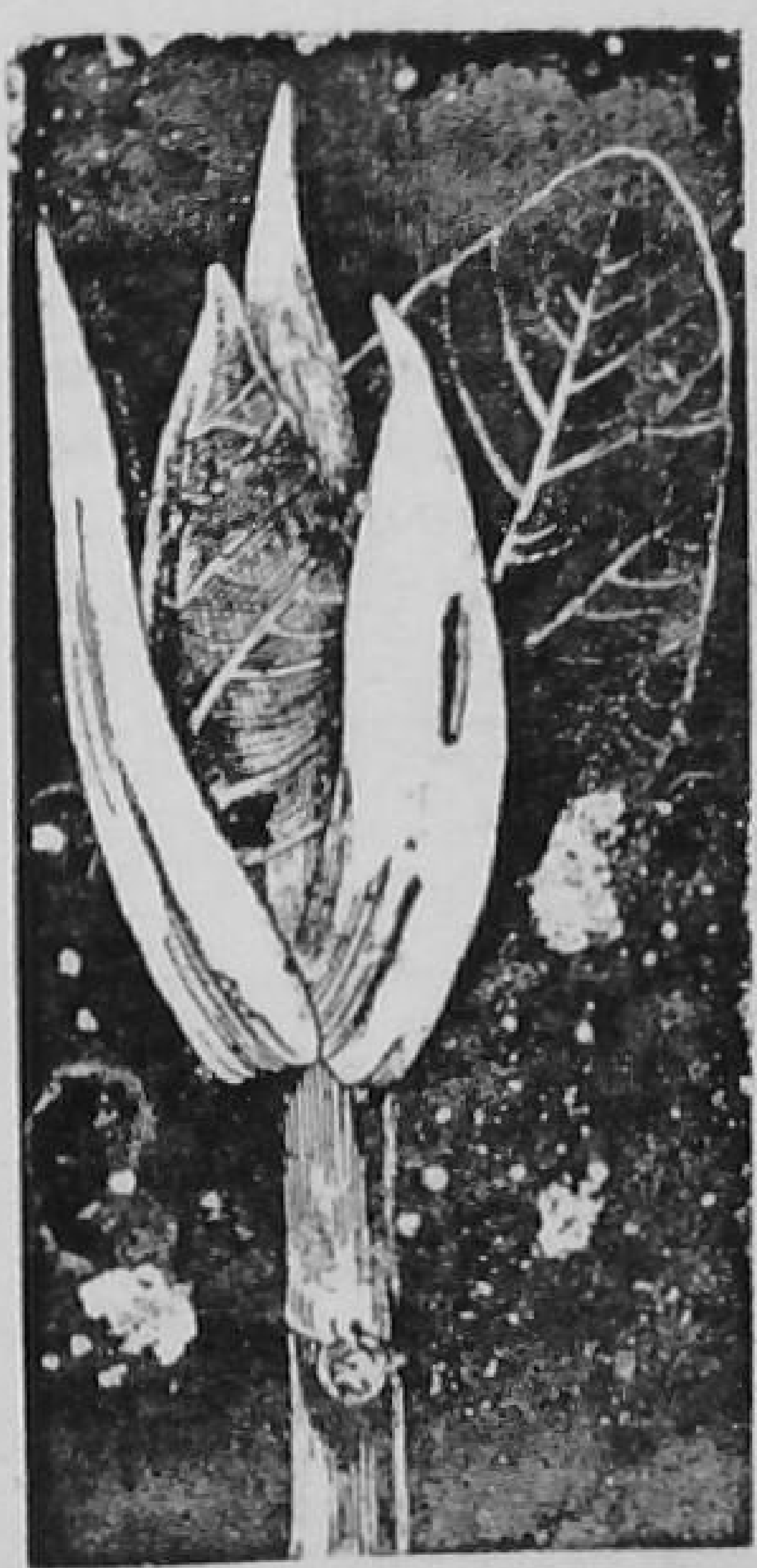


Fig. 66. Terminal bud of a banyan.

Fig. 67. Terminal bud of *Ficus*.

In dicotyledonous plants the leaf base is usually short and small. It may be fleshy and thickened in some cases and then it is called a **pulvinus.** In the majority of monocotyledonous plants and in a few dicotyledonous plants of the family Umbelliferæ they have **sheathing bases.** For example, the leaves in *Musa*, ginger and turmeric possess sheathing bases which over-lap one another and form stem like body. In the majority of plants however leaves have only the blade and the petiole and not the sheath. A small minority have the blade only, without the petiole

and the sheath. In grasses, leaves have only blade and sheath, but no petiole, except in bamboo.

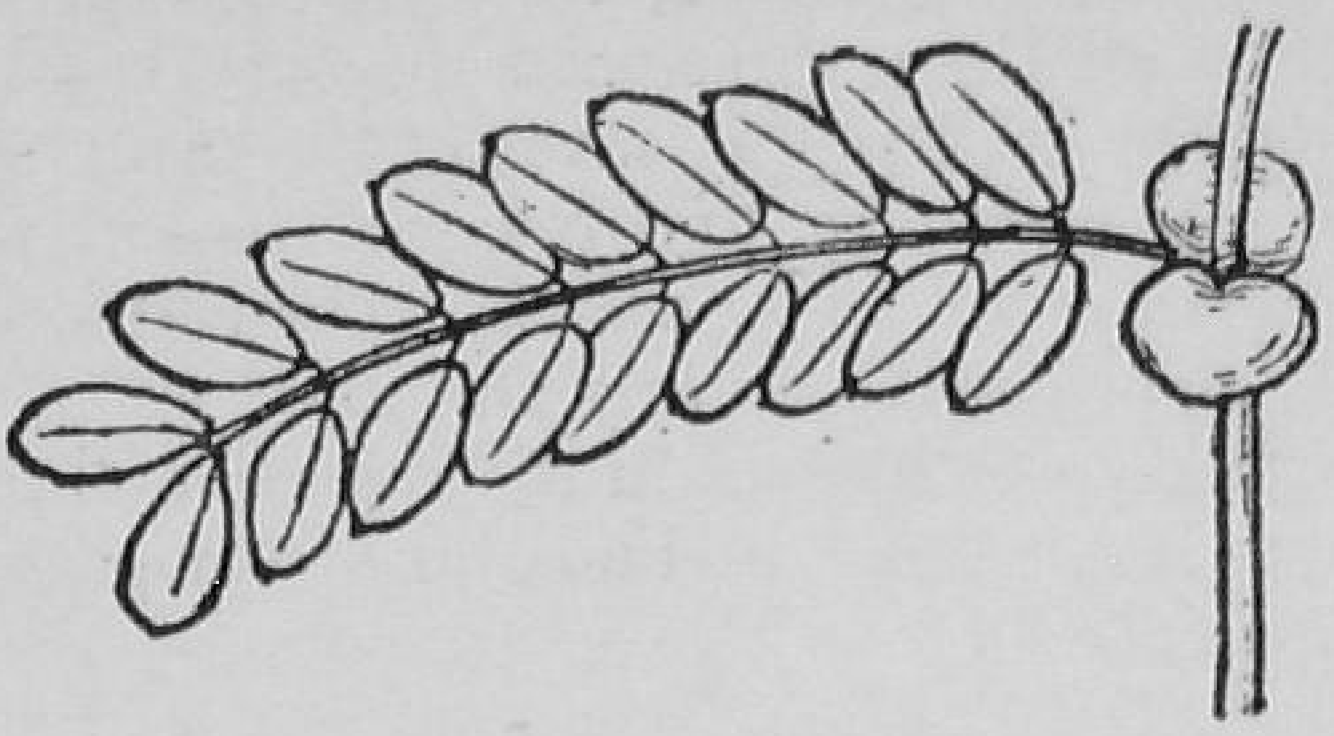


Fig. 68. Leaf of *Cassia auriculata* with large semi-lunar stipules.

Stipules.—We often see two lateral outgrowths growing out from the leaf base, one on each side, and these are called **stipules.** In the vast majority of plants the stipules are small, and in some they are not developed at all. They are very conspicuous and large in some plants, such as *Ficus benghalensis* (Banyan), Jak,

Fig. 69. Ochraceous stipule of Polygonum.

and other species (Figs. 66, 67). The stipules may be of different size and shape as described below.

(i) **Free and lateral** stipules are found in the plants belonging to the families Malvaceæ and Leguminosæ.

(ii) **Leafy** or **Foliaceous.**—The stipules are large and leaf-like in *Pisum* (Pea) *Lathyrus* and *Cassia auriculata* (Fig. 68).

(iii) **Ochraceous.**—The stipules in all the species of Polygonum are **tubular** and hence they are described as **ochraceous** or **ochrea** (Fig. 69).

(iv) **Interpetiolar.**—The stipules in the plants belonging to the family Rubiaceæ are **interpetiolar.** The leaves are opposite in these plants and the stipules of these leaves are united together between the petioles.

(v) **Adnate.**—When the two lateral stipules adhere to the base of the petiole as in Rose and *Arachis hypogaea* (ground-nut), they are termed **adnate.**

(vi) **Ligules.**—Structures resembling stipules are found in grass leaves at the junction of leaf base and blade. They are somewhat different in origin from the ordinary stipules and they are termed **ligules.**

Leaves are said to be **stipulate** if they have stipules, and **ex-stipulate** if without them. The presence or absence of stipules and their nature serve as useful guides in the classification of plants. Generally when the leaves are young the stipules are conspicuous, but as the leaves mature, they may fall off. When they fall off they are said to be **deciduous** and if they remain in position throughout the life period of the plant they are said to be **persistent.**

Modifications of stipules.—Stipules are sometimes modified to perform special functions.

(i) They are modified into **thorns** in *Acacia*, *Zizyphus*, *Euphorbia antiquorum* and *Pithecolobium dulce.*

(ii) Stipules are modified into **tendrils** in *Smilax.*

In *Ficus* species the stipules perform the special function of protecting the young bud and in Pea, they are very big and do the function of leaves which latter (leaflet) are modified into tendrils.

2. **Petiole.**—The petiole is a clylindrical structure varying in length, and with its upper surface often grooved or flattened. The function of the petiole is to hold the lamina as advantageously as possible, to get suitable illumination. In some plants petioles are capable of movement up and down, especially when the base of the leaf is thickened into a pulvinus. Petioles may have appendages on both the sides, as in orange leaf and in the leaf of *Filicium decipiens.* Then the petiole is described as a **winged petiole.** Occasionally the petioles twine round supports as in *Clematis smilacifolia* and *Solanum seaforthianum.*

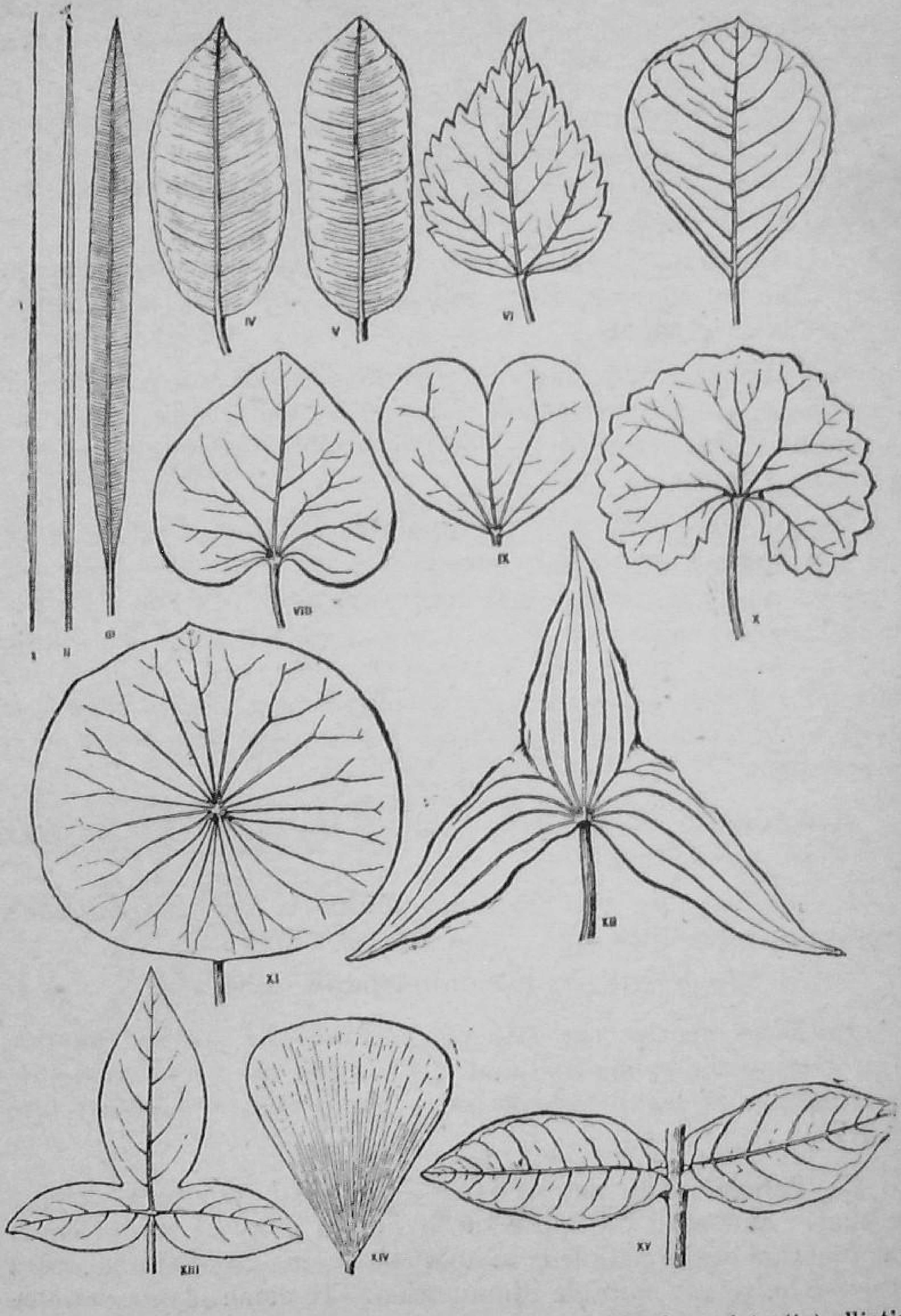


Fig. 70 Shape of leaves (i) acicular (ii) linear- (iii) lanceolate (iv) elliptic (v) oblong (vi) Ovate (vii) Obovate (viii) Cordate (ix) cleft (x) reniform (xi) rotund (xii) Sagittate (xiii) hastate (xiv) Cuneate (xv) auricled.

The petioles sometimes bear bladder-like swellings as in *Trapa bispinosa* and *Eichhornea crassipes*, (Water Hyacinth) an

exotic marsh weed now spread all over India. In some species of *Acacia* the petiole develops into a flat structure very much resembling the leaf and the blade does not develop. Such petioles are called **Phyllodes.** The phyllode assumes a vertical direction and not a horizontal one like the lamina. The petioles with the leaf-blades often fall off; but in *Quisqualis indica* the basal part of the leaf-stalk persists and becomes woody in vigorously growing branches.

3. Lamina.—The leaf-blade or the lamina, which for convenience is often designated shortly as a leaf, is always the essential part of a leaf because the formation as well as the transformation of organic matter takes place in it. The lamina is usually thin, flat and green. Ordinarily the leaf-blades maintain a horizontal position. The blade remains flat and stretched out, because it really consists of a framework of firm veins which support an expanse of thin, delicate tissues.

4. Shape of Leaves.—The shape of the lamina varies very much, but it can be referred to one or the other of the general shapes described below (Fig. 70).

A leaf is said to be :—

(i) **Acicular** when thin and long like a needle, e.g., Pine.

(ii) **Linear** when narrow and long as in grasses.

(iii) **Lanceolate** or lance shaped if the blade is somewhat broad at about the base and tapers towards the apex as in *Polygonum*, *Polyalthia longifolia*, and *Nerium*.

(iv) **Elliptic** if broad at the middle and tapers towards the apex and the base as in *Ficus elastica*.

(v) **Oblong** when the margins of a leaf are almost straight and the blade uniformly broad as in guava, Banyan and Calotropis.

(vi) **Ovate** when broad and round at the base and also tapering to a point at the apex as in *Hibiscus rosa-sinensis* and *Solanum nigrum*.

(vii) **Obovate** when the blade is broader at the apex and narrowed towards the base as in the leaflets of *Cassia obovata*.

(viii) **Cordate** if the lamina is hollowed out at the base and pointed at the apex so as to be roughly like the heart spot on a playing card, as in the leaves of *Thespesia populnea* and *Aristolochia bracteata*.

(ix) **Reniform** or kidney shaped when the leaf is cordate but with the apex rounded and somewhat broader than long as for e.g., in *Centella asiatica*.

(x) **Rotund** or round as in *Nelumbium* when the leaf has an orbicular shape.

(xi) **Sagittate** when the leaf blade is like an arrow head in its shape as in some Aroideæ and *Sagittaria sagittaefolia*.

(xii) **Hastate** when the basal lobes of a blade are straight and at right angles to the blade as in *Ipomoea aquatica*.

(xiii) **Auricled** if the basal lobes of a blade are rounded and prominent as in *Calotropis*.

(xiv) **Cuneate** when broad at the apex and pointed towards the base as in *Oxalis*.

5. **Margin of Leaves.**—The following terms are applied in describing the leaf margins :—

(i) **Entire**—when the margin of a leaf is quite even without any cut or indentations, as in Banyan leaf.

Fig. 71. Margin of leaves: (i) entire (ii) repand (iii) dentate (iv) serrate (v) crenate.

(ii) **Repand** or wavy when it is entire and wavy as in *Polyalthia longifolia*.

(iii) **Dentate** when the margin is cut up into distinct and prominent teeth as in *Hibiscus rosa-sinensis*.

(iv) **Crenate** when the margin possesses teeth that are rounded as in *Bryophyllum calycinum*, *Centella asiatica* and *Stachytarpheta indica*, (vide Fig. 71).

(v) **Serrate** if the teeth are small and directed upwards as in *Acalypha indica*.

(vi) **Lobed** when the leaves have deep indentations in their margins. For instance, leaves of cotton, *Hibiscus ficulneus* and *Ricinus communis* (castor) are such ones. These are said to be **lobed.** (Fig. 72).

(vii) **Cleft** when the cuts are deeper as in *Lactuca*.

(viii) **Partite** when the indentations reach almost the base of the leaf as in *Jatropha multifida*.

(ix) **Pinnately Lobed** when lobes are found or both sides along the midrib as in the leaves of *Lactuca runcinata*. (Fig. 72).

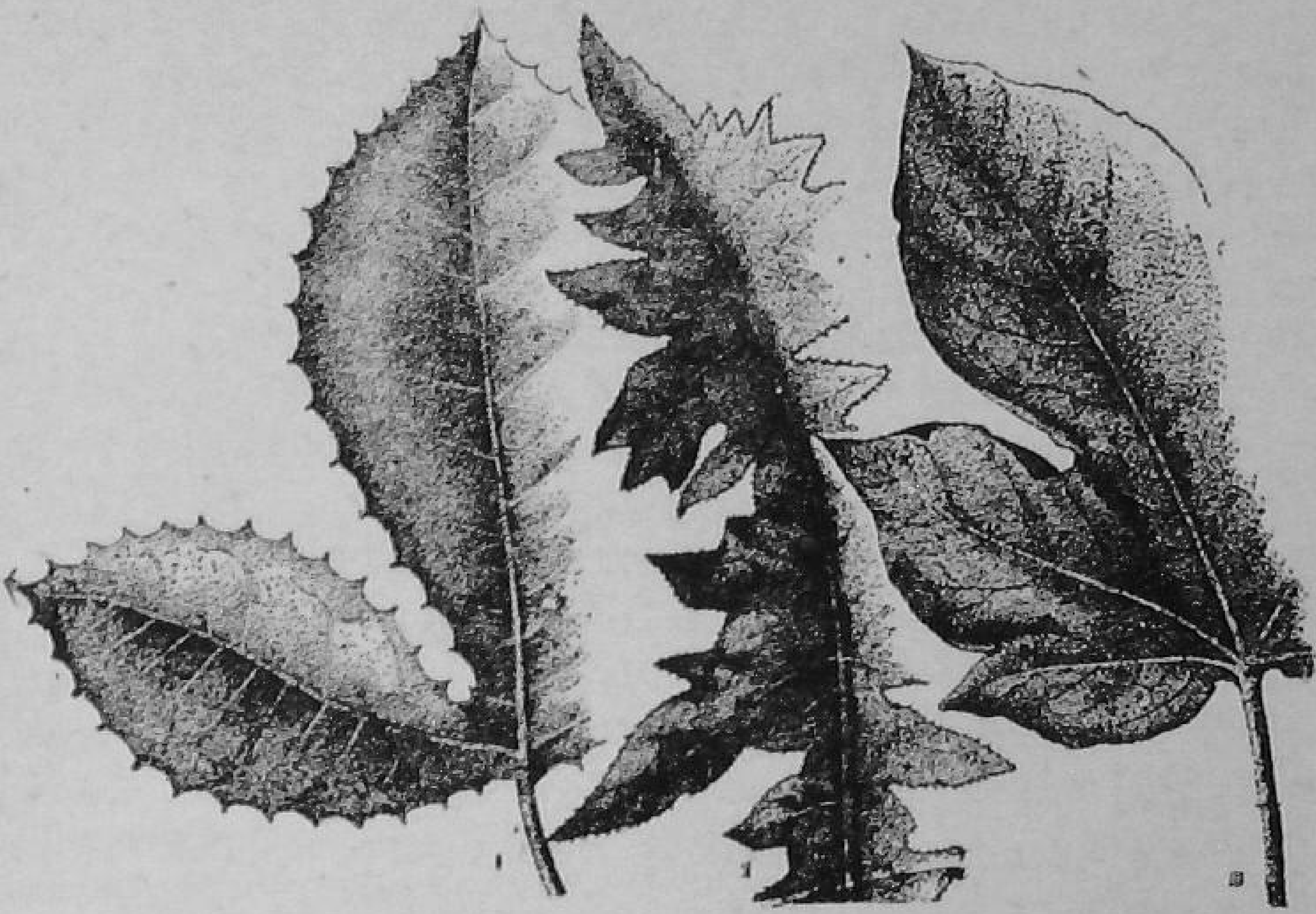


Fig. 72. Lobed eaves: (i) palmately lobed (ii) pinnately lobed (iii) Palmately lolbed.

(x) **Palmately Lobed** when the lobes are spread out like the fingers of a hand as in *Hibiscus ficulneus* and *Jatropha*. (Fig. 72).

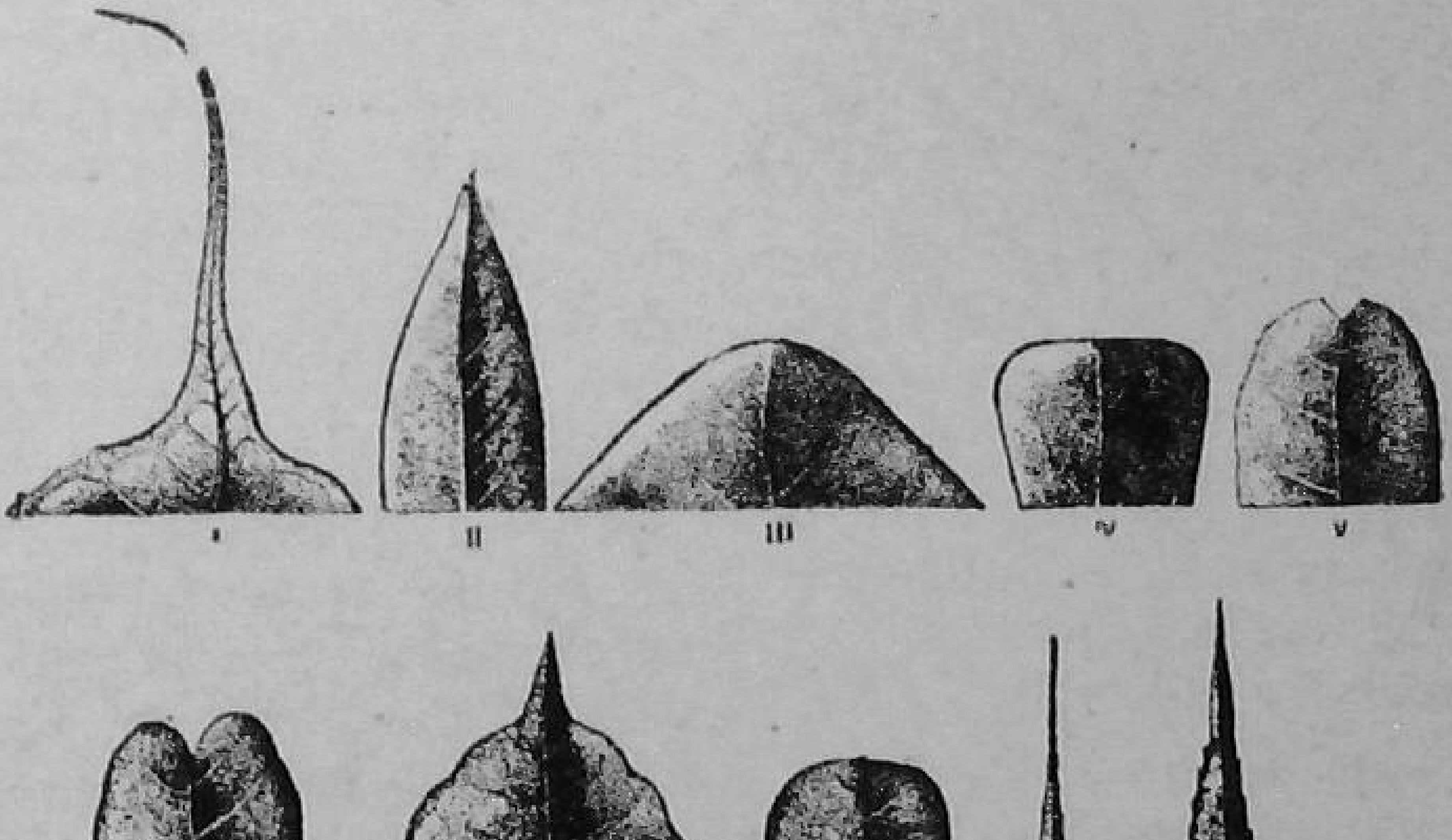


Fig. 73. Apex of leaves: (i) Acuminate (ii) acute (iii) obtuse (iv) truncate (v) retuse (vi) emarginate (vii) cuspidate (viii) mucronate (ix) and (x) spinous.

6. Apex of Leaves.—The terms used in describing the apex of the leaves are as follows :—(See Fig. 73.)

(i) **Acuminate** if it tapers to a fine point gradually as in the leaves of *Dolichos Lablab* and *Ficus religiosa.*

(ii) **Acute** if it is merely pointed as in the apex of mango leaf.

(iii) **Obtuse** if the apex is round and blunt as in the Banyan leaf.

(iv) **Truncate** if the apex is straight as though cut off as in *Portulaca.*

(v) **Retuse** if there is a shallow notch at the top.

(vi) **Emarginate** if there is a deep notch at the top as in *Sapindus emarginatus.*

(vii) **Cuspidate** if the apex is broad and abruptly pointed as of a cusp as in *Ficus elastica.*

(viii) **Mucronate** if the midrib is prolonged as a short point beyond the lamina as in *Cassia.*

(ix) **Spinous** if the apex ends in a spine as in Date palm.

7. Venation of Leaves.—In the vast majority of leaves a prominent midrib runs up from the base of the blade to its apex dividing the leaf into two equal symmetrical halves. From this mid-rib branch ribs of successively smaller size pass towards the margins of the leaves. The branching of the veins are carried to such an extent that the final small veins are hardly visible. Further these smaller, delicate ultimate branches unite so as to form a fine net work traversing the thinner areas of the blade. In the leaves of dicotyledons, the venation is usually in the form of a delicate network and hence it is called **reticulate venation.** (Fig. 74.) This reticulate venation prevents the tearing of the margins of leaves,

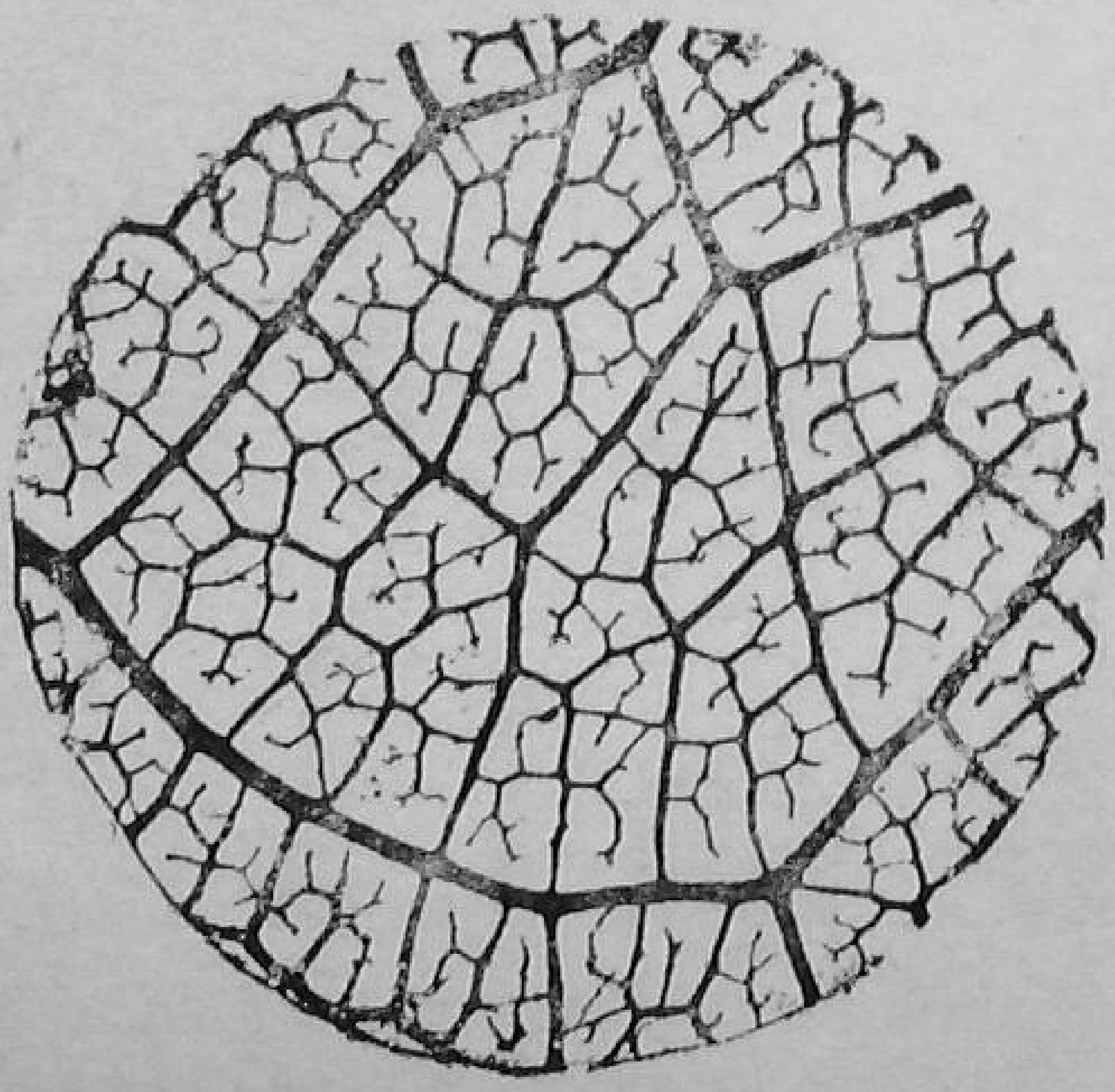


Fig. 74. The net work of veins in *Ficus* leaf.

even in strong winds. In some leaves, as in Antigonon the net-work at the margin is more marked and consists of distinctly curved veins. Such leaves do not get torn in their margins even to the smallest extent. When reticulation is absent at the margins of leaves, the margins usually get torn and the leaf blade becomes torn into small pieces, as in the leaves of *Musa paradisiaca.* In the vast majority of monocotyledons the veins run parallel to one another though they are connected laterally by small transverse branches. This venation is termed **parallel venation.**

8. Vernation or prefoliation.—When leaves are young they are folded in the bud in various ways. The folding may be considered with reference to the folding of each leaf on itself or folding with reference to one another. The former is termed **ptyxis** and the latter **vernation.**

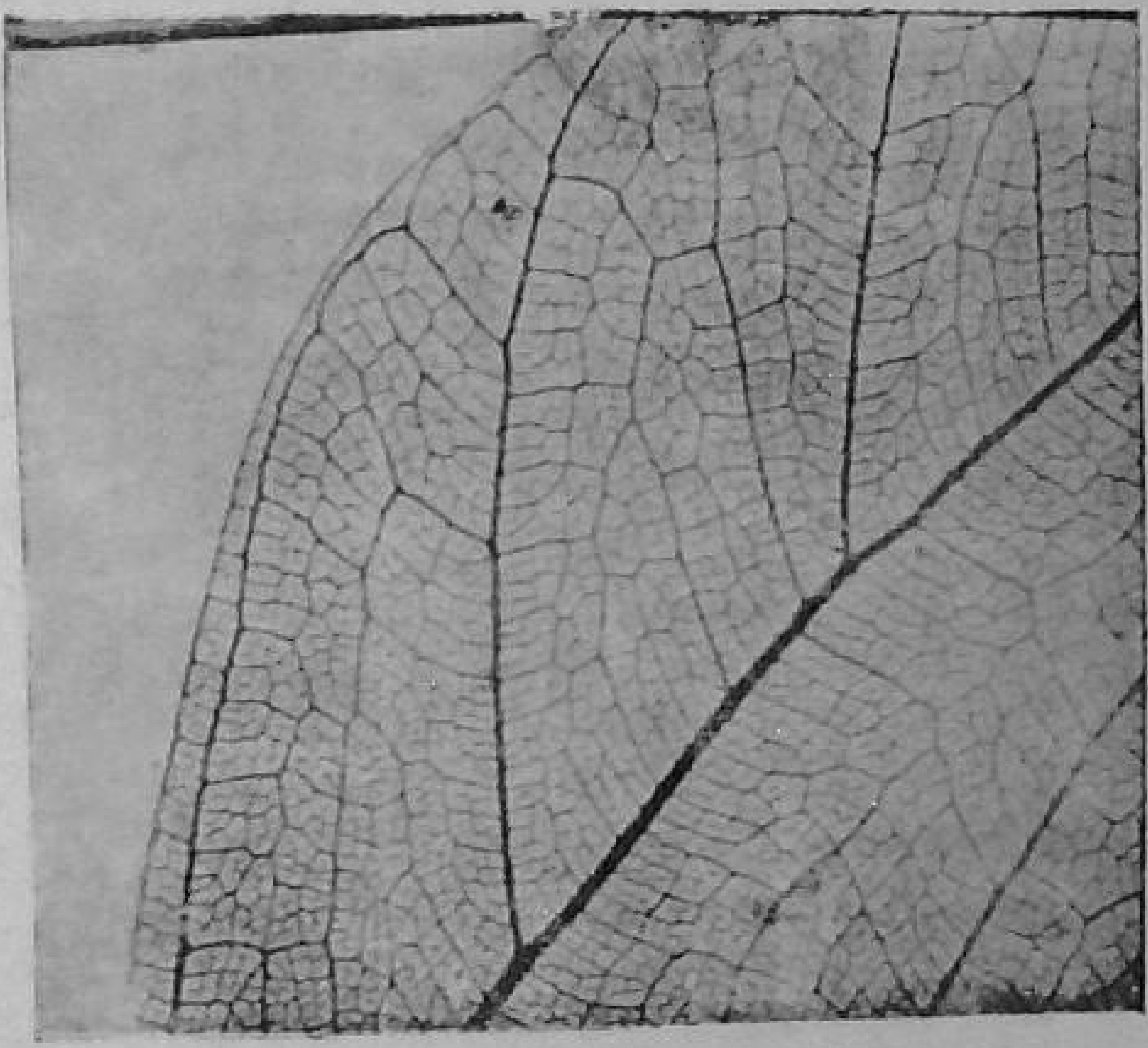


Fig. 75. Reticulate venation in *Ficus* leaf.

Ptyxis or folding of leaves on themselves may be any of the following types :—(Fig 76).

(i) **Conduplicate.**—In many plants the two halves of the blade are folded along the midrib with their upper surfaces facing each other as in *Anona* and *Thespesia populnea.*

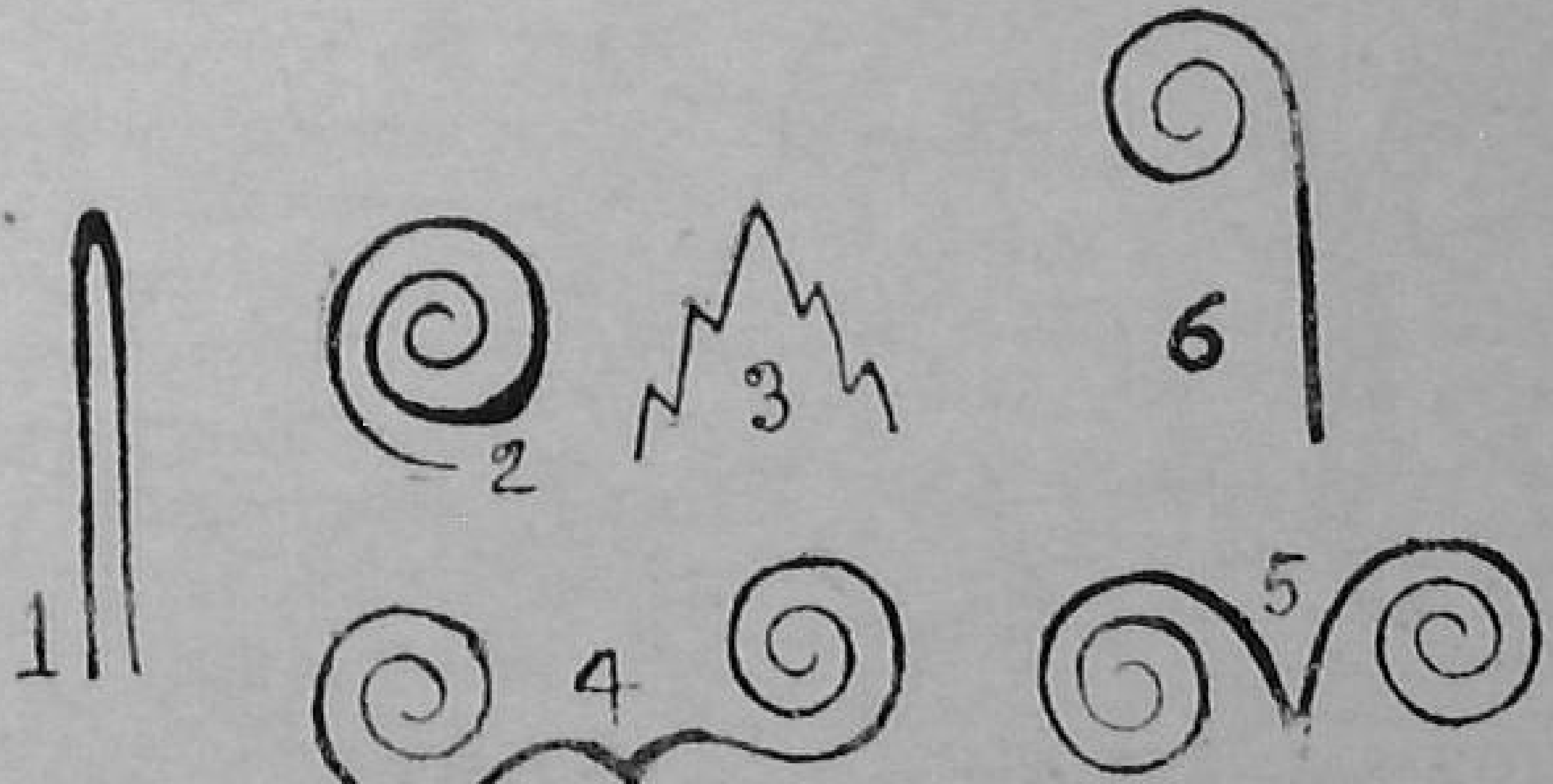


Fig. 76. Ptyxis : (i) Conduplicate (ii) Convolute (iii) Plicate (iv) involute (v) revolute (vi) circinnate.

(ii) **Convolute.**—When the leaf blade is rolled on itself from one margin to the other, so that one margin being rolled towards the midrib remains inside and the other outside it, it is termed convolute. The leaves in *Musa paradisiaca* and *Canna indica* are convolute when young.

(iii) **Involute.**—When both the margins are rolled inwards towards the midrib so that the upper side is inside, it is termed involute, e.g., young leaves of *Nymphaea*, *Nelumbium*, *Ottelia*, *Viola*, *Commelina benghalensis* and *Terminalia Catappa*.

(iv) **Revolute.**—The folding is revolute when both the margins are rolled towards the midrib so that the lower surface is inside. The leaves of *Nerium odorum* are revolute when young.

(v) **Plicate.**—The folding is termed plicate when the blade is folded upon itself several times as in coconut, palmyra and castor leaves.

(vi) **Circinnate.**—When the leaf is curled up from the apex towards the base as in a watch spring it is termed circinnate, e.g., young leaves of Ferns.

We have also to consider **Vernation** or the folding of leaves in a bud with respect to one another.

(i) **Valvate.**—If the leaves in a whorl merely meet by their margins, then they are said to be valvate.

(ii) **Imbricate.**—When the margins overlap one another then the vernation is imbricate.

(iii) **Equitant.**—Where two conduplicate leaves enclose each other.

Vernation will be fully dealt with in connection with flower.

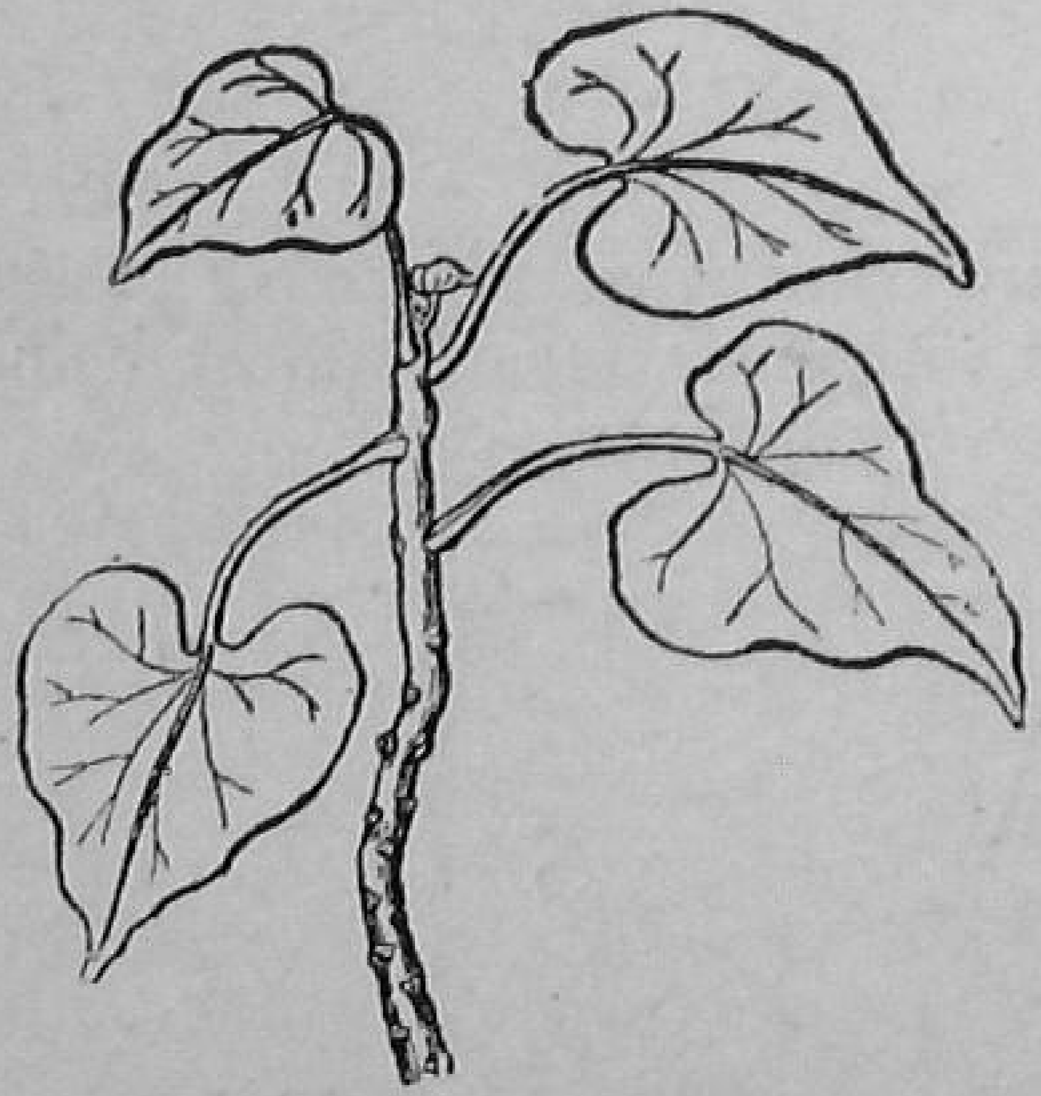


Fig. 77. Simple leaves of *Thespesia populnea*.

9. Simple and compound leaves.—In the leaves of *Cassia auriculata*, *Cleome* and *Gynandropsis* the cuts are so deep that the blade is cut into distinct pieces, and a piece can be detached without in any way affecting the other pieces. Such leaves as these are called **compound leaves,** in contrast to leaves like those of *Thespesia* and *Hibiscus* which are termed **simple** (Fig. 77). The distinct pieces of a compound leaf may be disposed **pinnately**

as in *Cassia auriculata,* or **palmately** as in *Eriodendron* or *Gynandropsis.*

A leaf may be simply compound as in *Cassia auriculata* and end abruptly with an even number of leaflets, or it may end in a leaflet and have an odd number of leaflets. The former is described as **paripinnately** compound and the latter **imparipinnately** compound. Sometimes the leaf is said to be bi or tripinnately compound or **decompound** (Fig. 78).

Bi-pinnate leaves are those in which the axis has secondary branches with distinct leaflets pinnately arranged as in *Delonix regia, Cardiospermum,* etc. **Tri-pinnate** leaves are those in which there is an additional or third series of branches bearing the leaflets as in *Moringa.* A leaf cut into numerous compound divisions as in *Panax* or *Coriandrum* is termed **Decompound.**

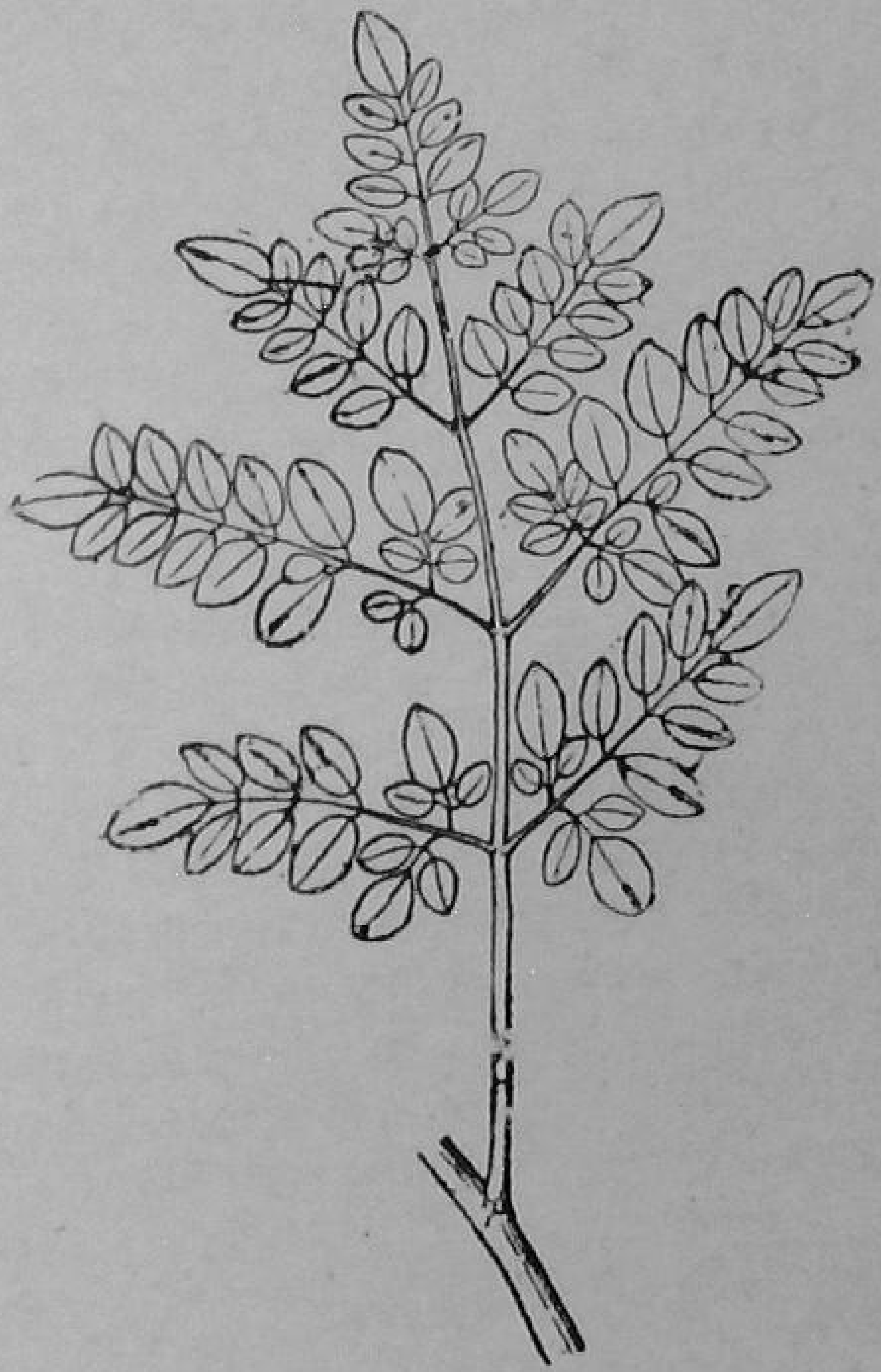


Fig. 78. Decompound leaf.

A compound leaf is derived from a simple leaf by the development of deep indentations of various degrees in the lamina. Though a compound leaf sometimes closely resembles a small branch, it shows all the characteristics of a simple leaf For example, (i) a compound leaf bears a bud in its axil (ii) since the leaflets of a compound leaf are derived by cuts in a simple lamina, there are no buds in the axils of leaflets. (iii) the tip of a compound leaf ends in leaflets only and there are no buds equivalent to apical buds of branches. (iv) In some cases a compound leaf may resemble a branch. The branch arises from the axil of a leaf whereas a compound leaf arises from a node and bears a branch or buds in its axil.

10. Phyllotaxy.—An examination of a leafy branch will show that leaves do not arise from it haphazard, but are definitely arranged. The position of leaves with regard to light is such that all the leaves get sufficient light without shading one another to any large extent. In other words, we see that plants adopt every possible means of placing their leaves in such a position that they are least interfered with by their neighbours, and their surface gets the greatest amount of exposure to light. The commonest methods of leaf arrangement or **phyllotaxy** are the **alternate** and the **opposite** plans (Figs. 79 and 81).

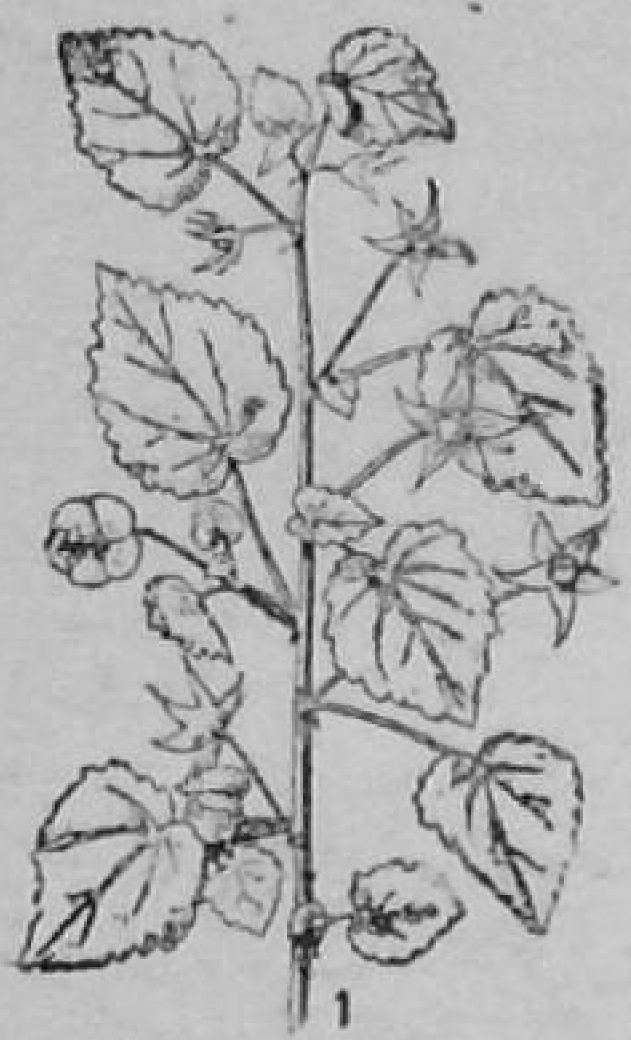


Fig. 79. Altternate phyllotaxy

(i) The phyllotaxy is said to be **alternate or scattered** when only one leaf is found at the node. In this case the leaves will be found to form a spiral about the stem, as in *Hibiscus, rosa-sinensis, Abutilon, Anona, Tephrosia* and mango.

(ii) When the leaves spring in pairs facing each other at a node, they are said to be **opposite.** Leaves are opposite in *Morinda, Calotropis, Vinca* and Pomegranate.

(iii) The leaves are said to be **verticillate** or **whorled** if there are more than two leaves at a node. They are whorled in *Nerium, Alstonia* and *Clerodendron* (Figi. 80).

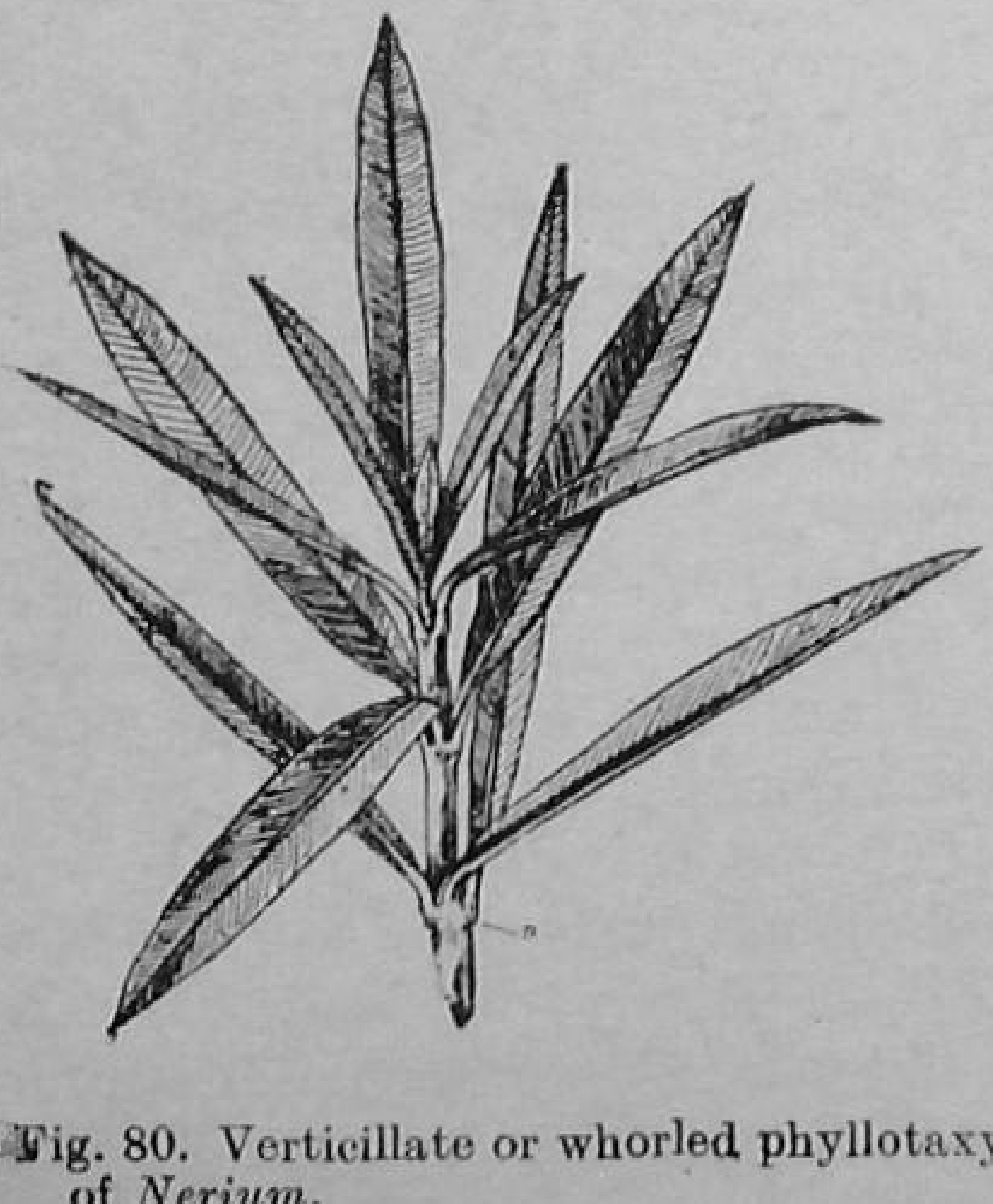


Fig. 80. Verticillate or whorled phyllotaxy of *Nerium*.

In stems with alternate leaves, the leaves will be in vertical rows. Between two successive leaves on the same vertical line, a number of leaves will be found but at different heights and different positions. For example, in the normally growing branches of *Thespesia populnea* or *Abutilon indicum* any leaf chosen will be exactly above or below the sixth leaf and the five leaves spirally arranged round the stem. The spiral will consist of two complete

turns round the stem and the first leaf will be separated from the second by a space equal to two fifths of the circumference, that is to say 144° apart. In a spiral of five leaves we get five vertical rows arranged round the stem at equal distances. These vertical rows or lines are called **orthostiches.** The simplest case of arrangement of leaves occurs in grasses. The successive leaves stand one half way around the circumference of the stem from those next above and below, so as to form two vertical rows bringing the third, leaf above the first. The arrangement is called **distichous.** When the leaves are arranged in three ortho stiches and the divergence of leaves is one third the arrangement is termed **tristichous.** The arrangement already described as occurring in *Abutilon* and *Thespesia* is **pentastichous** and the divergence is two fifths. Other higher divergences also occur. In some, as in *Carica papaya* it is 3/8 and it may be 5/13 as in *Spondias mangifera*. The fractions used to designate the phyllotaxy denote the divergence as well as the number of leaves and cycles. For example: 1/2 denotes one complete cycle, and two leaves and the divergence is 360°×½ or 180°; 2/5 spiral denotes a divergence of 360°×2/5 or 144°, two spirals and five leaves. In other words, in these fractions, the numerator denotes the number of spirals and the denominator the leaves or orthostiches.

Fig. 81. Opposite phyllotaxy of *Calotropis.*

When the leaves are opposite, the successive pairs will be at right angles to one another (Fig. 81). In other words, the leaves at any one node will be across the leaves of the nodes above and below it. This arrangement of leaves is termed **decussate.** If the leaves are in a whorl, the leaves of the alternate nodes are exactly one above the other, and the leaves of the successive nodes will be found on different vertical lines side by side.

Leaf Mosaic.—Leaves manage to avoid shading one another not only by means of phyllotaxy but also by other means. If we look at the leaves on the shoots of *Acalypha*, Papaya or *Amarantus* from above, the leaves will be found arranged in rows round the stem in such a way as to utilise the space to the best

advantage, without shading each other (Fig. 82). The leaves below are not shaded by those above, because the petioles of the former are longer than those of the latter. Further, size of the leaf blade also has some bearing on the disposition of leaves round the stem. If the leaves at the node are broad, the number of leaves in the whorl will be less, but if the leaves are narrow more leaves spring from the node to form the whorl. Whatever the number of rows around the stem, all the leaves get their share of light, because the rows are not likely to shade one another. But in the same row, leaves above are likely to throw those below into shade. As a matter of fact this does not happen so as to interfere with one another. By the adaptation of the length of the blade shading is avoided.

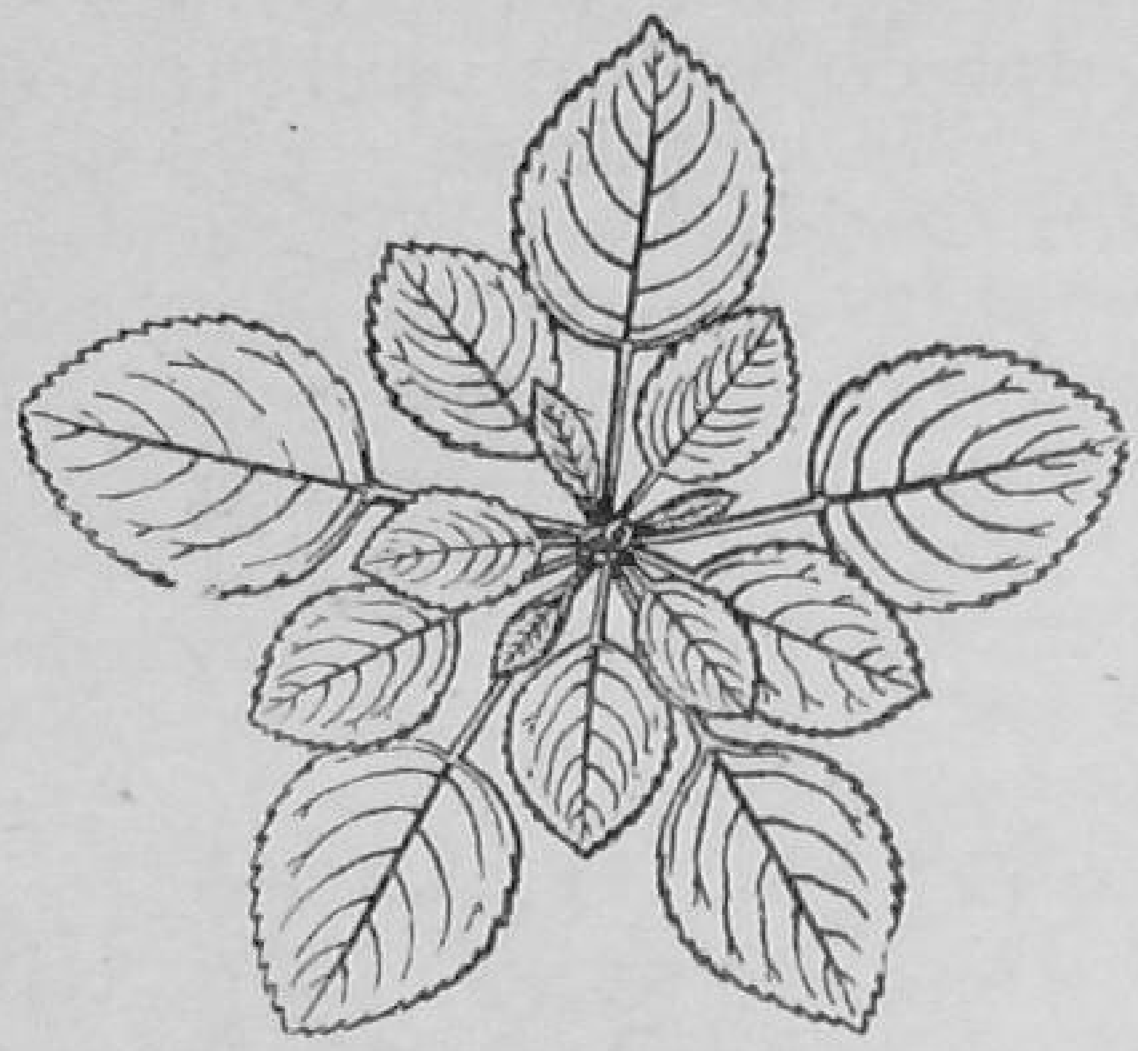


Fig. 82. Leaf Mosaic.

In some cases the leaf surfaces present beautiful mosaics. For example in many Solanaceous plants such as *Solanum nigrum Datura fastuosa* and *Physalis minima* the leaves are not at all uniform in size and so the leaves arrange themselves in mosaic fashion.

Leaf Rosette.—Many plants of the family Composite may be cited as examples for the rosette habit of the leaves. The leaves in *Lactuca runcinata*, *Taraxacum officinale* and those in some species of a *Blumea* are mostly confined to the base of the plant. In other words, the leaves are radical. In all these plants the leaves are narrow at least in their lower portions and so they are disposed round the stem so as to form a rosette. The introduced plant *Sempervivum* (Fig. 83) affords an excellent example for the rosette arrangement of leaves. It is easy to give more examples, for instance, *Trapa bispinosa*, *Elytraria crenata* and *Elephantopus scaber*.

Arrangement of leaves in trees.—The same principle namely, that the leaves should spread themselves, so as to enable all the leaves to be illuminated and at the same time, avoid shading one another is very well brought home by the heads of trees. For instance, the heads of trees such as those of Banyan are generally

found covered by leaves externally so as to form a frame work or covering with as few gaps as possible. To enable all the leaves

Fig. 83. Leaf rosette of *Sempervivum*.

to obtain sufficient light this is the best possible arrangement. If we look at the head of the same tree from inside and from near its trunk towards the branches, we find large spaces between boughs and twigs and no leaves are found distributed in these gaps.

Modifications of leaves.—Like a stipule and the petiole, the leaf blade is also often modified (i) For instance, in the insectivorous plants *Drosera*, *Utricularia* and *Nepenthes* the leaves show distinct modifications; in *Drosera* the leaves are provided with glandular hairs secreting mucilage in such profusion as to imprison the insects, when the hairs come in contact with them. The leaves of *Utricularia* are modified into bladders with trap doors to catch insects. In the pitcher plant *Nepenthes*, the leaves are prolonged at the apex into long processes ending in cups or pitchers. The pitchers contain a liquid. The insects are allured

by pitchers, so that they may fall into them and get digested by the water contained therein.

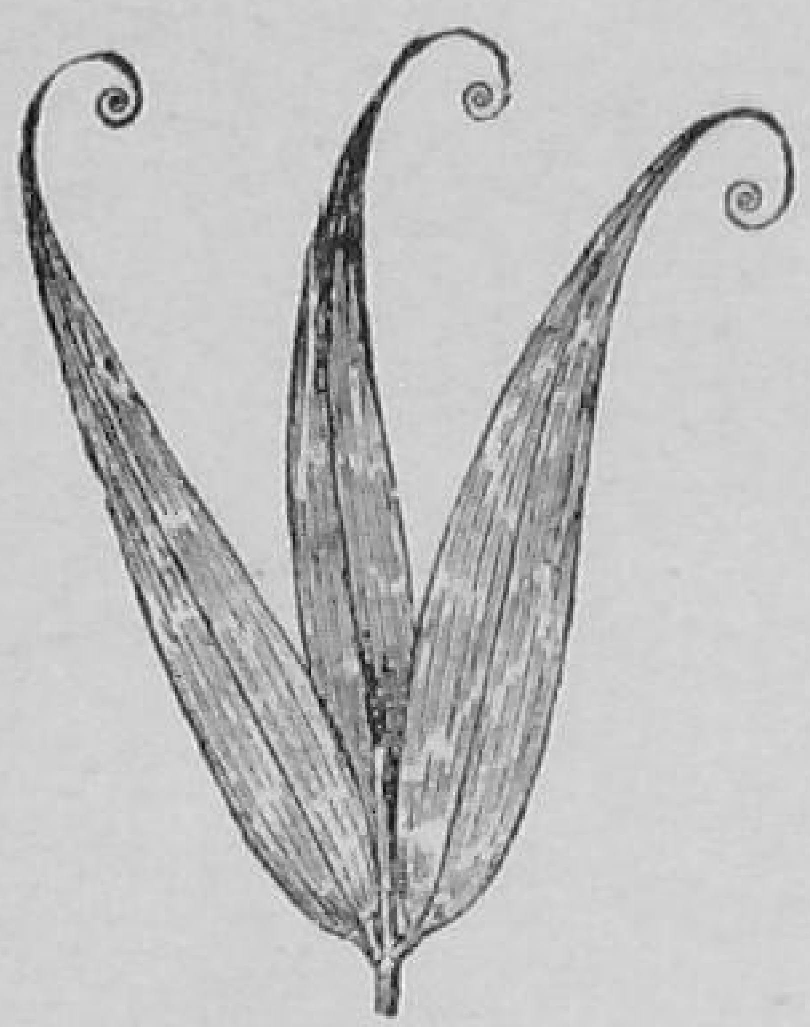


Fig. 84. Leaf tip modified into tendril in *Gloriosa superba*.

(ii) In some plants, the leaves are modified into spines. In *Opuntia* (Prickly pear) the leaves and axillary buds are modified into spines. In *Agave* and *Aloe* the leaves are thick and fleshy and end in spines. They serve the purpose of storing water and food materials.

(iii) Leaves are sometimes modified into tendrils. Leaflets are modified into tendrils in *Pisum* (Pea). Leaf tip is modified into tendril in *Gloriosa* (Fig. 84).

(iv) Scaly leaves protecting buds are in some cases modified leaves. In *Swietenia Mahogany*, *Mangifera indica* (mango) and *Rhododendron* the leaves are modified into scales to protect the dormant buds. In the case of all kinds of underground stems, the leaves on the main stem under the soil become scales.

(v) The petiole of a leaf may be flattened out to function as leaf while the lamina is reduced in size or absent. These flattened petioles are termed **Phyllodes,** e.g., *Acacia melanoxylon*

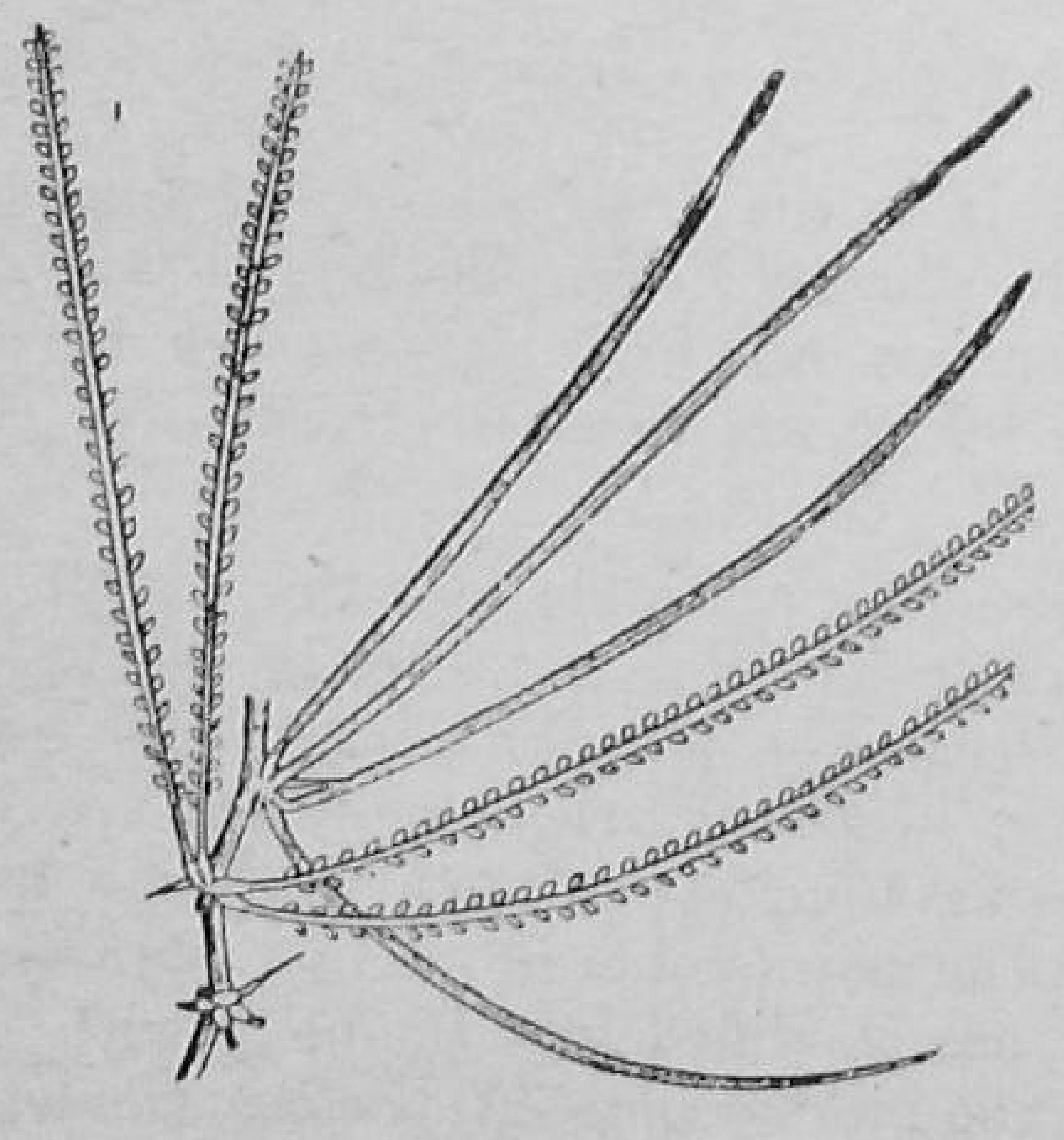


Fig. 85. Phyllodes of *Parkinsonia aculeata*.

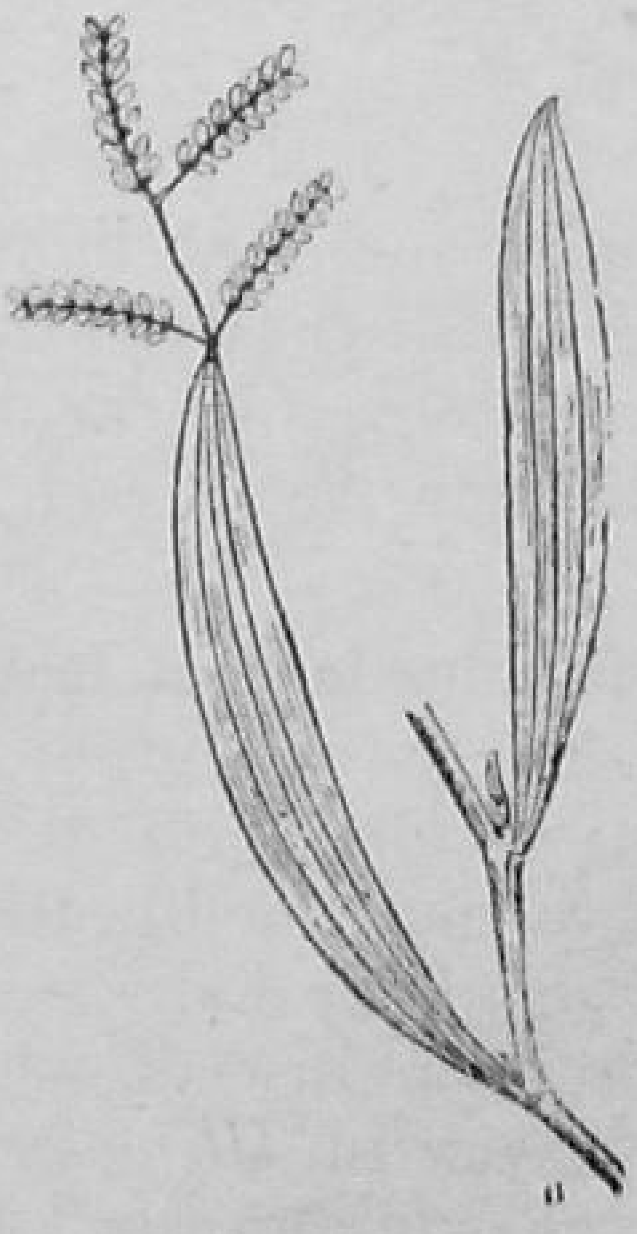


Fig. 86. Phyllodes of *Acacia melanoxylon*.

and *Parkinsonia aculeata.* In the latter case, the leaves are bipinnately compound and the main rachis ends in a spine while the secondary raches are modified into phyllodes (Fig. 85, 86).

(vi) The floral parts such as bracts, calyx, corolla and andrœcium and gynæcium are all considered as modifications of leaves in the course of evolution of devices for sexual propagation.

12. Leaf Fall.—Although the primary function of the leaves is the same in all plants, they show much diversity in various features. In size they vary from a fraction of an inch as in *Dentella repens* to several feet as in Palms. Similarly, they present various shapes from linear to circular shapes. As regards duration, leaves are temporary, lasting but one season in the majority of plants. In some cases, such as in *Delonix regia, Erythrina indica*, all the leaves are shed at the end of a season leaving the tree bare. Fresh leaves are developed by the beginning of next season. These are described as deciduous. The leaves may be persistent as in mango, jack and neem. The leaves fall down by the formation of an **abscision** layer at the junction of the leaf base with the axis. This layer cuts off the supply of food material to the leaf.

Summary.

LEAF.

Leaf base.
(1) Sheathing as in grasses, *Musa* and *Canna*.
(2) Pulvinus in Leguminous-plants.
(3) Absent in many cases.

Petiole.
(1) Absent in cases such as grasses.
(2) Flattened into phyllode as in *Parkinsonia*.
(3) Tendrillar as in *Clematis*.

Lamina.
Is described in regard to—
(1) general shape.
(2) margin.
(3) apex.
(4) Lobing.
(5) Simple or compound.
(6) Venation.
(7) Modifications.

Arrangements in stem-phyllotaxy—
(1) Alternate.
(2) Opposite.
(3) Whorled.

In bud—
(1) Ptyxis.
Conduplicate.
Convolute.
Involute.
Revolute.
Plicate.
Circinnate.
(2) Vernation.
Valvate.
Imbricate.
Equitant.

Appendage.
Stipules (Types)—
(1) Free.
(2) Foliaceous.
(3) Ochraceous.
(4) Interpetiolar.
(5) Adnate.
(6) Ligules.
(7) Tendrillar.
(8) Spinous.

Modifications.
(entire leaf)
(1) To catch insects and digest them—
in insectivorous plants.
(2) Into spines.
(3) Into tendrils.
(4) Into scales.

CHAPTER VII

THE INFLORESCENCE

The shoot system, during the greater part of a year consists of foliage bearing branches constituting the vegetative region. At definite seasons in a year with periodic intervals, floral branches make their appearance. The flowers or flower clusters appearing in plants form the floral region. A flower, judging from its position, is morphologically a branch bearing floral leaves. In many plants flowers arise singly from the axils of ordinary green leaves, as in *Thespesia populnea*, and then the leaf subtending the flower does not differ from other foliage leaves. But, if flowers arise in regular succession one after the other from the axils of leaves then the leaves become smaller and also different in appearance from the foliage leaves. Such reduced and modified leaves are termed **bracts.**

Flowers arising in large numbers on an axis or on several axes are collectively referred to as an **inflorescence.** If we carefully

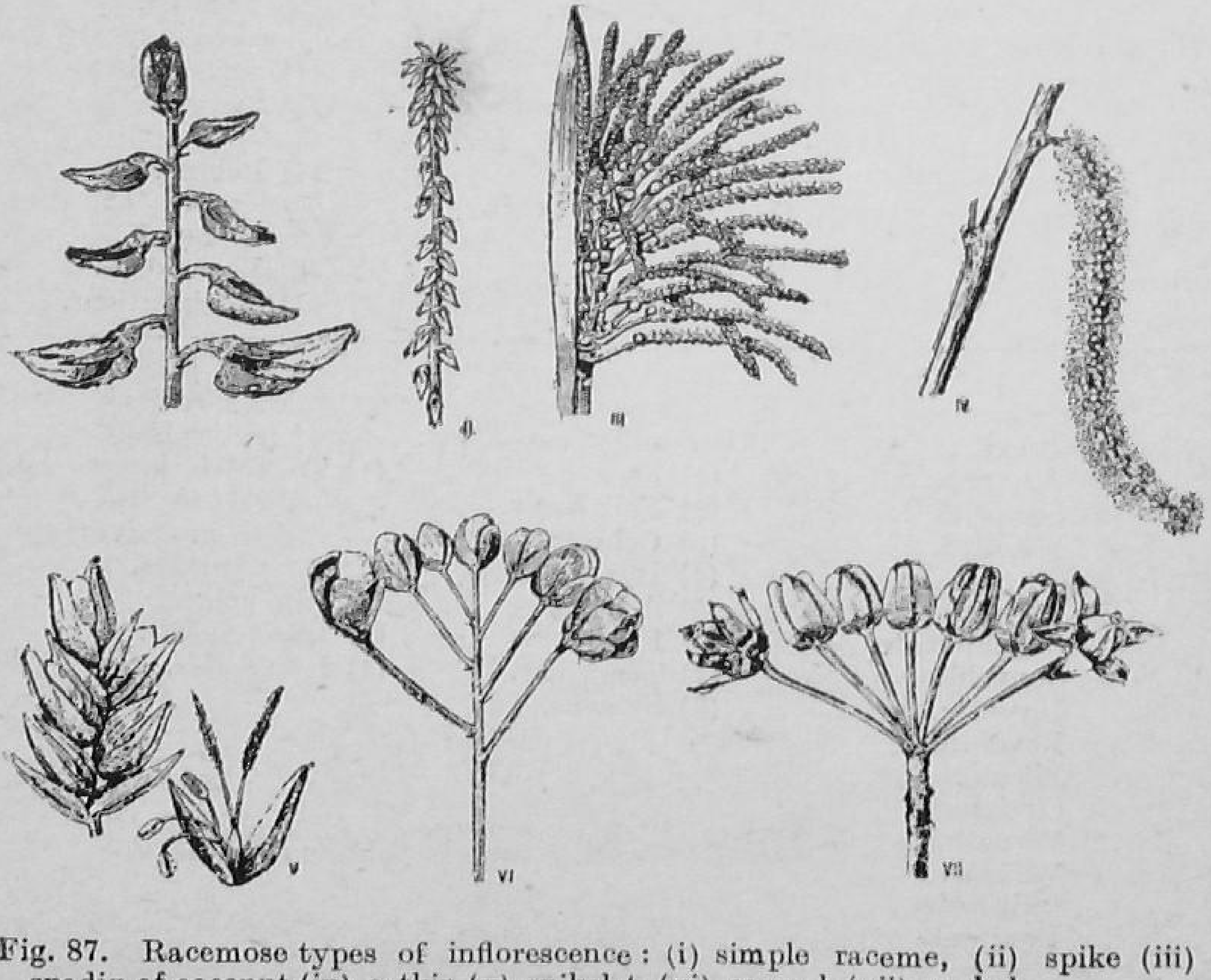


Fig. 87. Racemose types of inflorescence: (i) simple raceme, (ii) spike (iii) spadix of coconut (iv) catkin (v) spikelet, (vi) corymb (vii) umbel.

examine a number of inflorescences from different plants, we find that they are of various kinds. In some plants, as in *Crotalaria juncea* (Fig. 87), the main axis may be simple and unbranched, bearing flowers throughout its length. The inflorescence may consist of several branches, secondary, tertiary and so on bearing flowers. The naked stalk of a solitary flower or the naked basal portion of the main axis of an inflorescence is called the **peduncle,** whilst the flower bearing portion of the axis is termed a **rachis.** The stalk of an individual flower by which it is attached to the axis is called a **pedicel** (Fig. 87).

Racemose Inflorescence.

Owing to variations in the arrangement of flowers and also of branching of the axis in inflorescences we must necessarily have different kinds of inflorescence. For the sake of convenience distinct types are recognised and different names are given to them. (Fig. 87).

(i) **Raceme.**—This is most common type of inflorescence and seen in *Crotalaria, Sesbania and Tephrosia.* In all these plants flowers are borne by an elongated axis in acropetal succession and all the flowers are stalked. Inflorescence of this kind is termed a **raceme** (Fig. 87-i). Sometimes we find on the elongated axis, instead of pedicelled flowers, racemes and then the inflorescence becomes a **compound raceme.** In these plants the pedicels are more or less, of the same length.

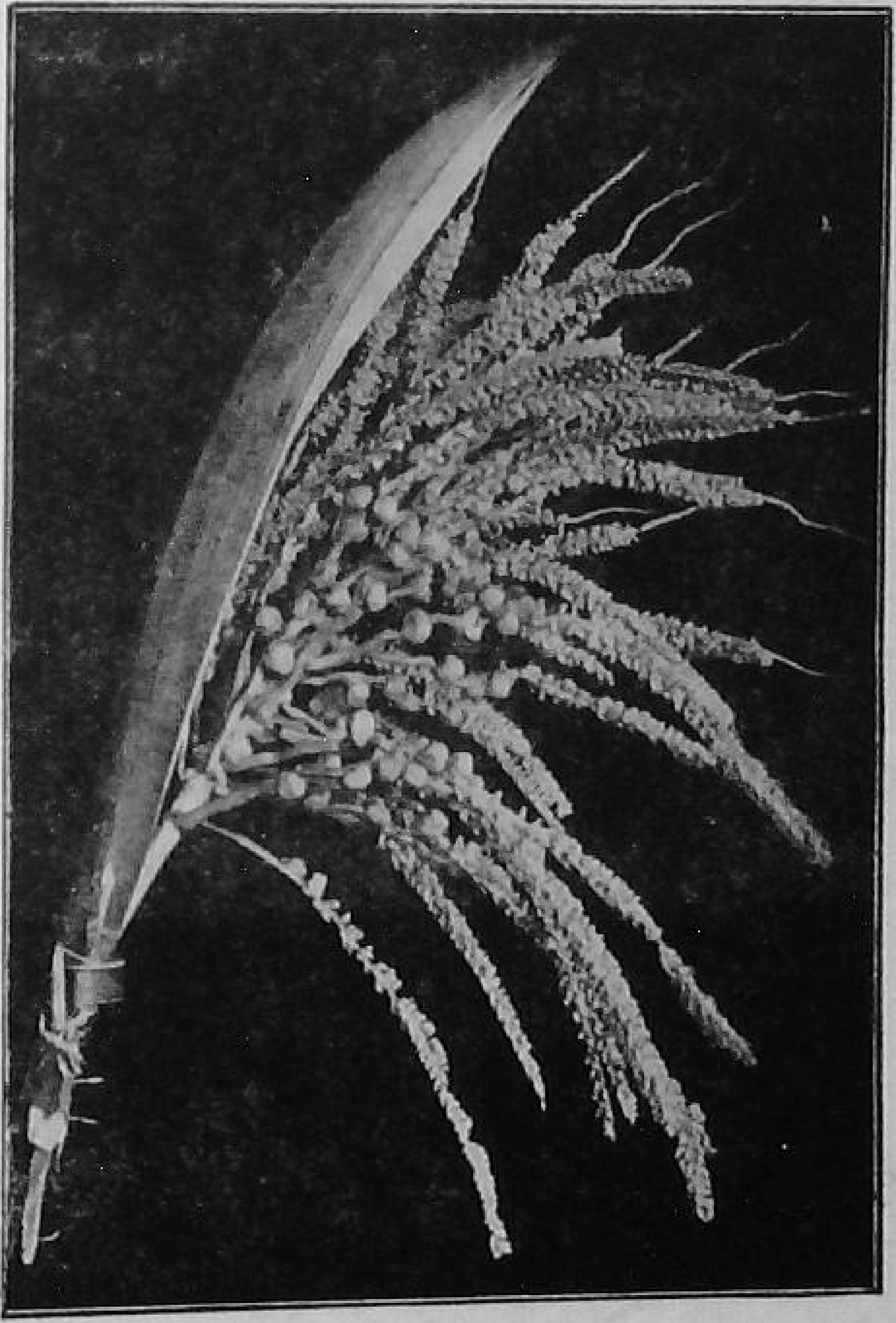


Fig. 88. Coconut inflorescence.

(ii) **Spike.**—Although flowers are pedicelled in many a plant, we find them in some plants without pedicels and sessile on the axis. For example, the flowers are sessile in the inflorescences of the plants *Amarantus, Digera, Achyranthes* and many other plants of the family Amarantaceae. This kind of inflorescence is known as a **spike** (Fig. 87-ii). Often the spike becomes a compound spike as in some grasses and Amaranths. The axis bears spikes instead of single flowers.

(iii) **Spikelet.**—The inflorescences of grasses are racemes or spikes in which the ultimate rachis ends into a **spikelet.** A spikelet is a spike with few flowers in which the special bracts or glumes are prominent while the perianth are reduced to lodicules or are absent. This reduced flower is termed a **floret.** A spikelet may consist of one floret only as in rice or as many as 7 to 8 florets as in ragi.

(iv) **Catkin.**—A spike with pendulous axis bearing unisexual flowers only as in mulberry, is termed a **catkin.**

(v) **Spadix.**—It is not unusual to find in some plants, as for instance, in *Colocasia, Amorphophallus* and other Aroideae, the axis of the spike becoming stout and fleshy and associated with it we usually find a large sheath or bract which is generally coloured and attractive. The axis is then called a **spadix** and the sheath a **spathe.** (Fig. 87-iii). In some plants the spadix becomes branched very much and the spathe also grows larger and is firmer in structure. This is the case in most palms, and the inflorescence of coconut may be cited as an example. (See Fig. 88).

(vi) **Corymb.**—In the inflorescences of *Gynandropsis pentaphylla* and *Cassia auriculata* the pedicels of the lower flowers are longer than those above and, therefore, all the flowers are at about the same level. This type of inflorescence is said to be a **corymb** (Fig. 87-vi). A few other examples of plants having corymbs are *Caesalpinia sepiaria, Cassia siamea* and *Ixora parviflora*

(vii) **Umbel.**—We often see flowers springing from the top of the peduncle instead of from an elongated rachis. The pedicels of flowers are attached to the summit of the peduncle and not all along the axis in continuation of the peduncle. This type of inflorescence is called an **Umbel** (Fig. 87-vii). If we have on the top of the peduncle umbels instead of pedicelled flowers, we describe it as a **compound umbel.** The inflorescence in

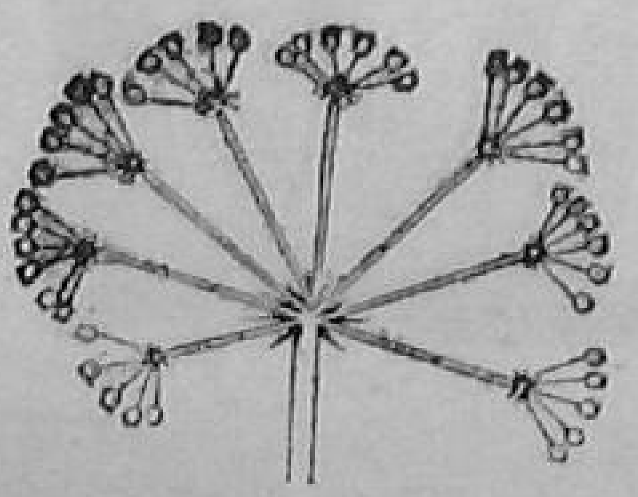


Fig. 90. Compound umbel.

coriander, onion, *Calotropis* and *Daemia* are umbels. In *Heracleum* and *Bupleurum* the inflorescences are compound umbels.

(viii) **Capitulum or Head.**—Sometimes as in the case of Sunflower, the peduncle enlarges and becomes a flat disk at its summit, and on the upper surface of this disk we find numerous sessile flowers. This kind of arrangement of flowers is called a **capitulum** or **head.** All plants of the family Compositae have heads. (Fig. 91 & 92). The head is really a spike with its rachis widened out into a disk to afford room for the flowers to be on it closely packed. Because of this crowding together, the flowers become small and therefore they are called florets. In a capitulum all the flowers may be alike as in *Vernonia* or as is more common, the florets of the circumference known as **ray-flowers** may differ in shape from those of the centre termed **disk florets.** The ray florets are generally **ligulate** and the disk florets **tubular.** The florets are often embraced by small scaly structures called **palea.** The palea are really bracts. In a head outside the ray florets we find rows of bracts at the circumference. These bracts constitute **involucre.** The heads of Sunflower, *Tridax* and *Zinnia* may be taken as examples.

Fig. 91. Head or Capitulum.

On comparing these types of inflorescence above described, we find them differing in certain respects and resembling in certain general features.

The raceme, the spike, spadix and catkin have long main rachis; Corymb and umbel have shortened main rachis. In the case of capitulum the main rachis is flattened. The raceme and the umbel both have pedicelled flowers whilst in the spike and the capitulum flowers are sessile. In all these four, the youngest flower is at the top or at the centre and oldest at the base or the circumference. Further, all the flowers are derived from the activity of the same growing point. **The axis, where distinct, is a monopodium.** So we may consider these four kinds of inflorescence as constituting a type and it is termed **botryose** or **racemose.** Owing to the continued activity of the growing point the number of flowers

that could be formed is not limited. So this type of inflorescence is also called **indefinite.** It is also termed **centripetal,** because the order of flowering is from the circumference to the centre.

Fig. 92. Sunflower (Head in flower.).

Cymose inflorescence.

In some plants the terminal growing point of the axis, instead of producing flowers in succession, terminates in a flower which is the first to blossom. Below this, lateral branches arise and they also end in flowers. The inflorescence in *Jasmine* plant is of this nature. In it we find a central flower with two lateral buds or flowers one on each side, the central one being older than the lateral. This really represents another type of inflorescence called **cymose.** The order of flowering in this type

being from apex to the base or centre to circumference, the inflorescence is called **centrifugal.** It is also called **definite.**

The cymose Inflorescence also presents variations in its mode of development. The inflorescence in *Jasmine* consisting of only three flowers may be considered to be a **simple cyme** (Fig. 93-i). But modifications occur. The lateral branches, instead of bearing single flowers possess in addition two one on each side. In other words, the lateral branches are distinct simple cymes, one on each side of the central older flower. This may be repeated two or three to several times. Such inflorescence as these are met with in several species of *Ipomoea* and *Clerodendron*. In some plants, as in *Wrightia* and *Nerium*, this process is repeated indefinitely. If the development of the lateral branches is regular, the inflorescence is called a **dichasium** (Fig. 93—ii).

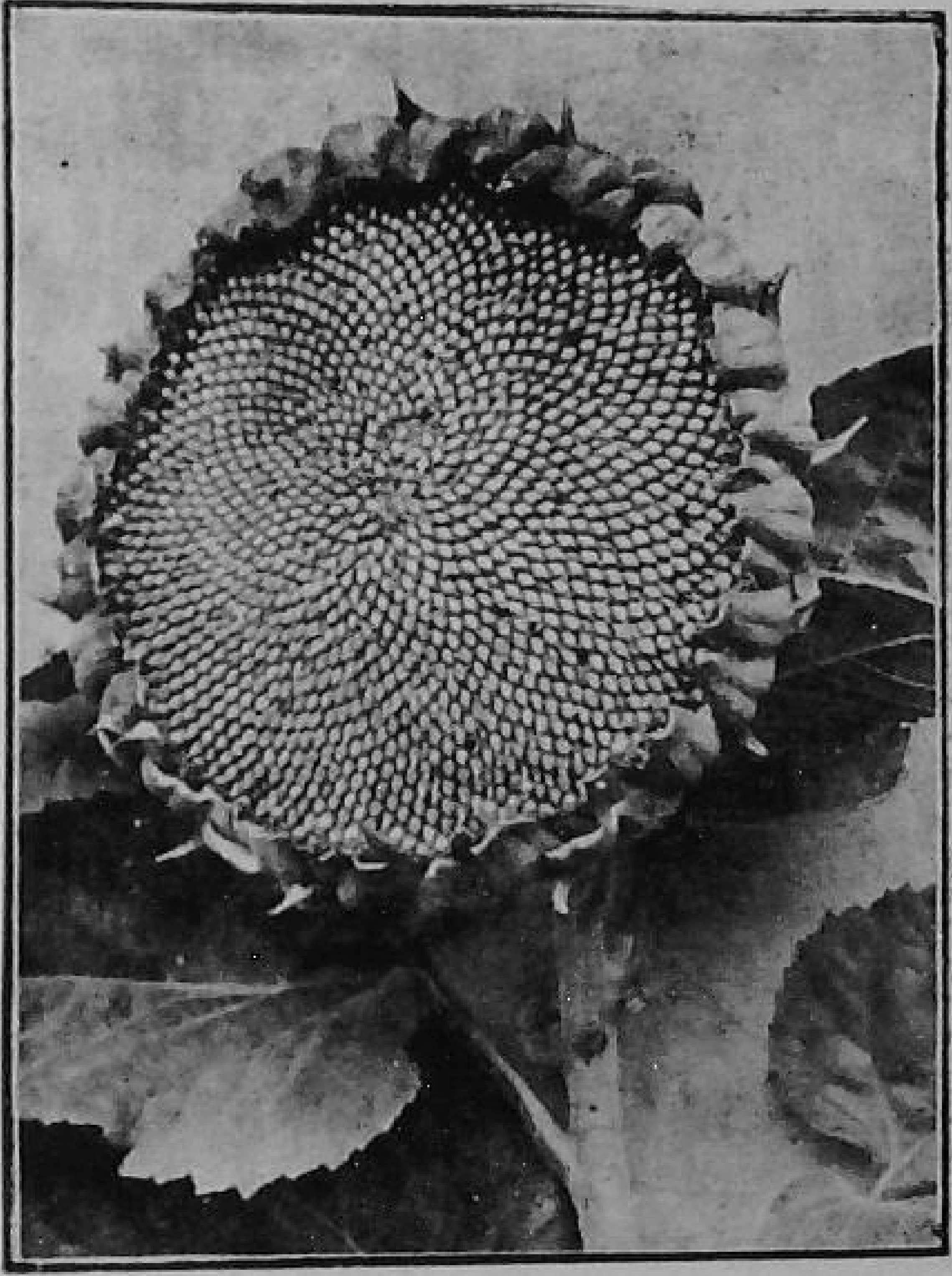


Fig. 93. Sunflower (Head in fruit).

The development of the lateral branches in the cyme is not always regular. Very often only one of the lateral branches develops, and again the suppression of a branch may be regularly all on the same side, or it may be alternate. The former type of cyme is fairly common in some plants of the family *Solanaceae* and the inflorescence is termed a **helicoid cyme** (Fig. 94). The other type in which the suppression occurs alternately to the right and left, as in *Heliotropium* (Boraginaccae) is called **scorpioid cyme** (Fig. 94).

In both these varieties of cymose inflorescence the floral axis is coiled at the free end when young but straightens itself later. The axis of the helicoid cyme when fully formed and straightened out looks like a raceme, but in reality it is a sympode and consequently the arrangement of the bracts would be different from

that in a raceme. In a helicoid cyme the bracts when present will be opposite the flowers and in the scorpoid cyme there will be two rows of bracts.

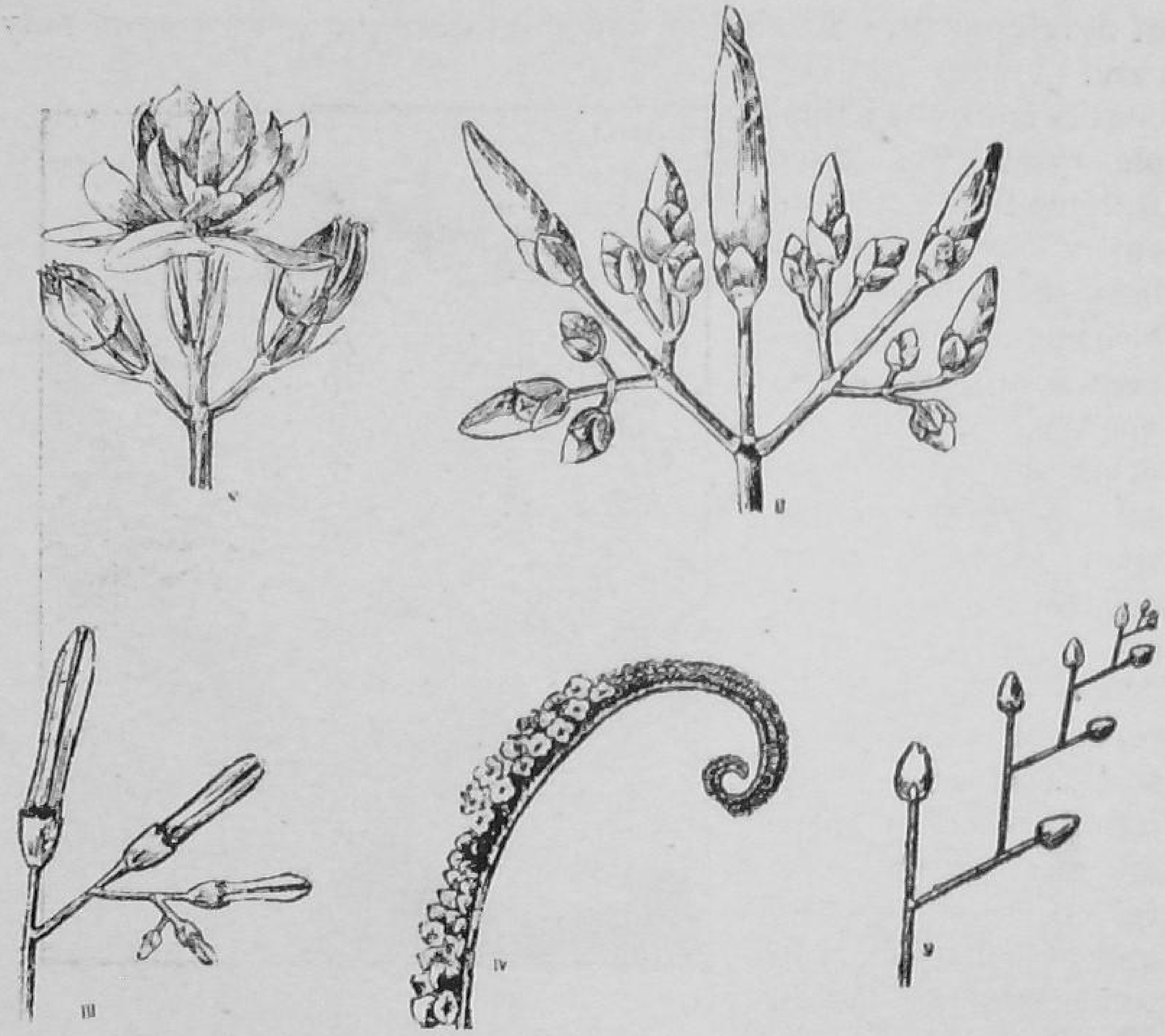


Fig. 94. Cymose inflorescence. (i) simple cyme. (ii) dichasial cyme (iii) helicoid cyme (iv) & (v) scorpioid cyme.

Sometimes two cymes spring at the nodes opposite to one another, as in *Ocimum* and other genera in the family Labiatae. In some cases as in *Leucas* and *Leonotis* the cymes made up of numerous flowers, become condensed and overlap the axis and look like a whorl of flowers ; so this kind of inflorescence is called a **false whorl** or **verticillaster** (Fig. 95).

These two types of inflorescence, botryose and cymose occur in plants generally, but in a plant only one of these types occurs. In other words, a plant will have either botryose or cymose type of inflorescence and never either the one or the other indifferently. But in some plants, such as *Melia* and *Azadirachta*, the inflorescence may be a mixed one, the flowers being in cymes and the branches racemes. Such inflorescences are termed **panicles.** Several grasses have panicles.

Special Types.

In some plants the top of the peduncle expands into a flat horizontal disk and the flowers become small and are immersed as it were in the disk. Such inflorescences are fairly common in *Dorstenia indica* and they are called **coenanthia**. If the coenanthium becomes hollow, as in *Ficus*, then it is called a **syconium** (Fig. No.)

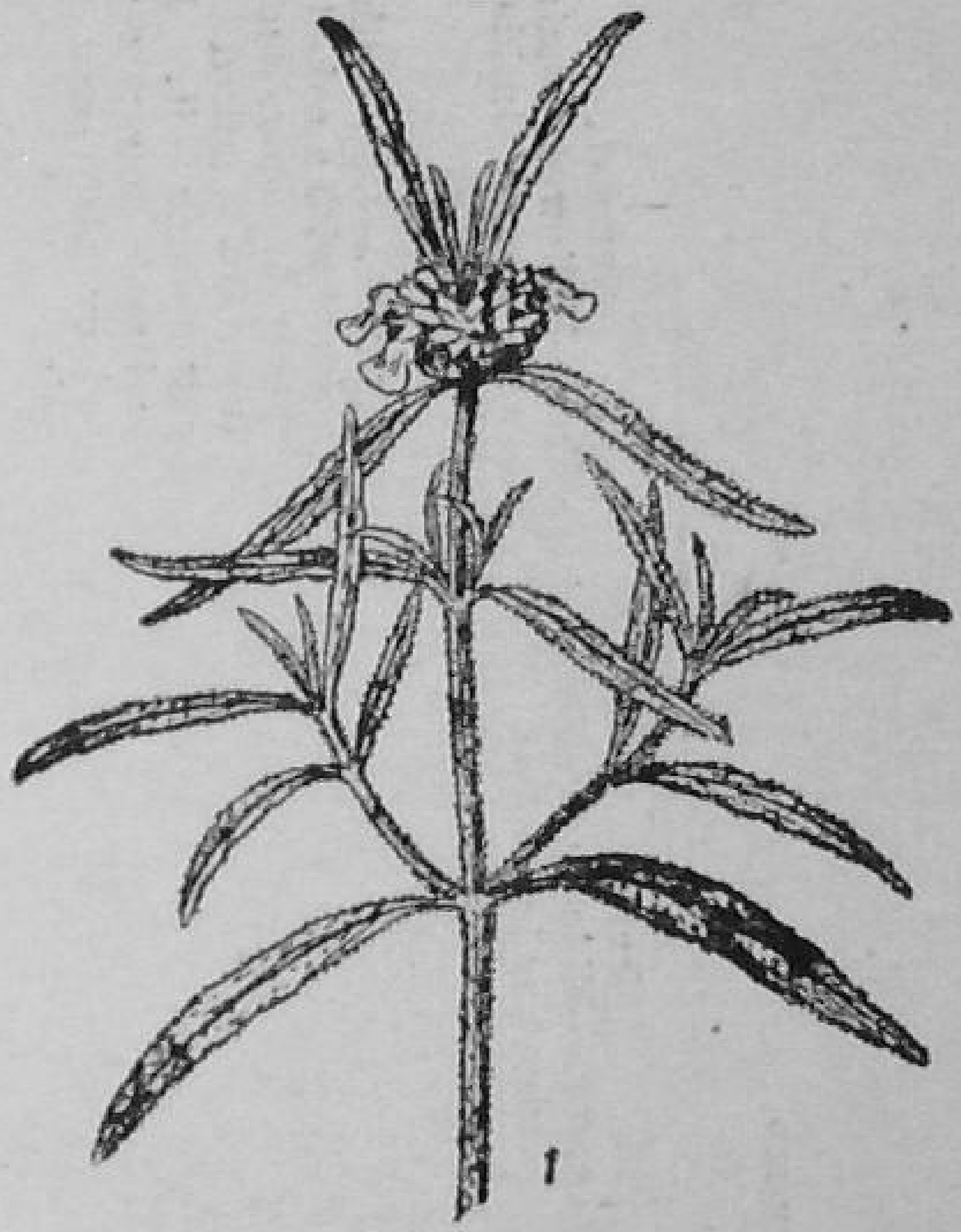


Fig. 95. Verticillaster.

(ii) **Cyathium.**—This type of inflorescence is found in *Euphborias* e.g. *Euphorbia heterophylla*, *E. pulcherimma* the *Poinsettia*. There is a cup like structure with a nectar gland to one side. In the centre of the cup is the female flower with a long stalk. It consists of the three carpelled pistil only and the other outer three whorls of a normal flower are absent. Thus the female flower is represented by the pistil only. Surrounding this single female flower are a number of male flowers. The male flowers also are reduced each to one stamen borne on a jointed stalk. Thus each stamen represents a male flower in which the other three whorls of a normal flower are absent. The development of all these flowers is cymose. (Fig. 96).

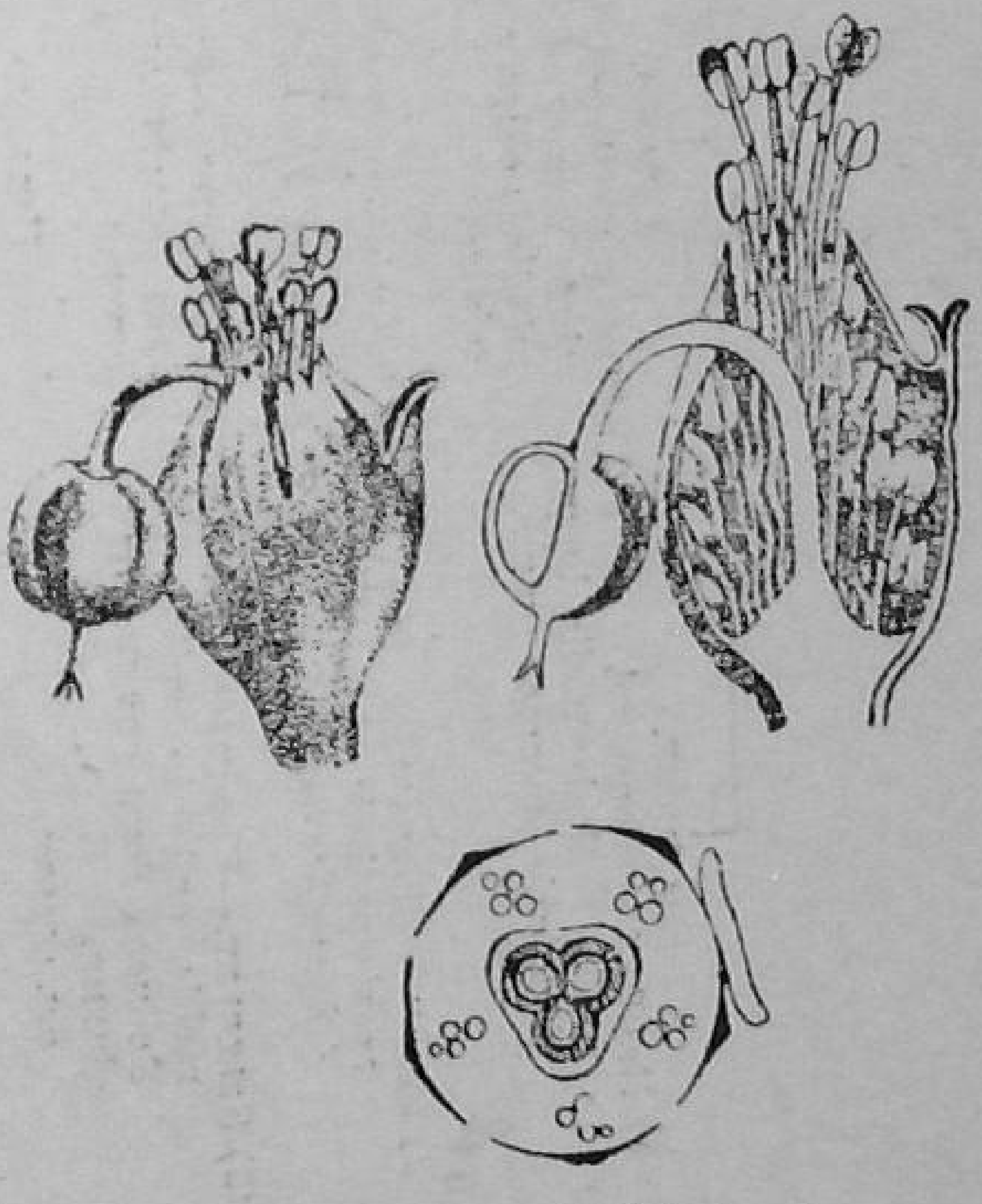


Fig. 96. Cyathium.

Summary.—The main kinds of inflorescence and their varieties may be tabulated as follows :

INFLORESCENCE.

RACEMOSE.	CYMOSE.	MIXED.	SPECIAL.
1) RACEME.—Elongated main rachis-Pedicel equally long *Crotalaria juncea* (sunn-hemp).	(1) SIMPLE CYME.—Axis with three flowers of which the middle is oldest: as in *Jasminum*.	PANICLE.—Mixedly cymose and racemose as in grasses.	(1) FIG.—Hollowed main axis with flowers inside as in *Ficus species*.
2) SPIKE.—Elongated main rachis-pedicels absent-*Achyranthes aspera*.	(2) DICHASIAL.—As above the process is repeated: *e.g. Nerium, Ipomoea carnea*.		(2) CYATHIUM.—Cup like involucre with a naked female flower to centre and number of naked males surrounding it. Female and male flowers represented by pistil and stamen only.
(3) SPIKELET.—Elongated main rachis end in spikelet: Reduced floret covered by glumes. e.g. grasses.	(3) MONOCHASIUM.—Sympodial axis; bracts opposite to flowers:		
	(*a*) HELICOID.—Suppression of development on one side only as in *Hamelia patens*.		
(4) CATKIN.—Elongated main rachis-pendulous with unisexual flowers. *e.g.* mulberry.			
(5) SPADIX.—Elongated fleshy axis associated with prominent large bract or spathe. *e. g.*, coconut.	(*b*) SCORPIOID.—Suppression of development on alternate sides: as in *Heliotropium indicum*.		
(6) CORYMB.—Shortened main axis with lower pedicels longer than the upper: as in *Cassia auriculata*.	(4) VERTICILLASTER.—Congested axillary cymes as in *Leuca-*		

(7) UMBEL.—Shortened main axis with pedicels starting apparently at one point as in coriander, onion.

(8) CAPITULUM.—Main axis flattened out to bear florets, as in members of the family Compositae.

CHAPTER VIII

THE FLOWER

A flower is a distinct organ existing for the purpose of producing fruit and seed, after the process of fertilisation. The various forms and the differences in colour seen in flowers, no doubt contribute towards this supreme end. We find foliage leaves always in plants, but flowers appear only periodically. This is because the work of nutrition goes on continuously in a plant, whilst the process of reproduction is not a continuous one. Further, for the formation of flowers a large amount of nutritive material must be available, and this is possible only when vegetative activity precedes the formation of flowers. In other words, **nutrition must precede propagation.**

Flower buds arise in the axils of leaves or bracts just like leaf buds. **So the flower buds are homologous with the leaf buds, and a flower with a leafy branch.** Sepals and petals borne by the floral axis are leaf like in their origin and development. Although sepals and petals are found on the axis in circles, there are also instances of flowers in which they are spirally arranged, recalling to our mind the phyllotaxy of the foliage leaves. From what is said above, we should not think that the floral leaves are derived from or are modified foliage leaves. It was the general opinion among the older morphologists who confined their observations mostly to flowering plants, that foliage leaves underwent extensive modifications in the course of evolution and began to develop sporangia, anther and ovules. But, in the light of what we know about the life histories of the lower vascular cryptogams and Muscineae, this view cannot be accepted. The truth seems to be that the primitive leaves must have served both the purposes, vegetation and propagation. In the course of evolution, differentiation must have taken place, so that a certain region of the shoot must have become purely vegetative forming only foliage leaves, while another produced sporangia.

Parts of a flower.—The flowers of *Tribulus terrestris* with which we have already become familiar, may be studied closely with a view to learn the arrangement of parts and other general features in flowers. Judging from the construction of this flower, we find that a flower consists of an axis bearing at its swollen free end or the **thalamus** the four parts, namely, **sepals, petals, stamens** and the **pistil** in a definite order. The outermost part of the flower is

the calyx and it consists of five, free, green narrow members, the sepals. Since the sepals are attached to the floral axis around it at the same level, they are spoken of as forming a circle or a **whorl.** The petals constituting corolla form the next whorl. They are yellow in colour. A flower in which the enveloping organs are in whorls or circles is said to be **cyclic.** These two organs of the flower are expanded and flat like leaves and serve the purpose of protecting the stamens and the pistil in the bud stage, and when in blossom are believed to be useful in securing pollination, if they are coloured or scented. So the calyx and the corolla are only **accessory organs,** while the stamens and the pistil constitute the **essential** organs. The sepals and the petals are collectively called the **perianth.** If these do not show much differentiation and look more or less alike, as if they formed a single series, the whole structure is termed a **perigone.**

The pistil is on the top of the thalamus in the *Tribulus* flower. Below this there are two whorls of stamens attached to the thalamus. The inner whorl consists of five longer stamens and these alternate with the five shorter outer whorl of stamens. At the base of the filament of each of the five shorter stamens there is a gland. As a general rule, in a flower the sepals alternate with the petals, the petals with the outer whorl of stamens and this with the inner whorl of stamens. **In all cyclic flowers the various whorls alternate, if the whorls have the same number of members in each.**

Some descriptive terms.

The *Tribulus* flower may be taken as an example of a typical symmetrical flower. It can be cut into two similar halves in more than one plane and hence it is termed **actinomorphic.** To describe a flower as symmetrical it must have the same number of members in the enveloping organs, calyx and corolla and need not be so in the essential organs. The flowers of *Dolichos* can be cut into two symmetrical halves in one plane only. Such flowers are described as **zygomorphic.** When the flowers cannot be cut into symmetrical halves in any plant, they are described as **asymmetrical.**

A flower is said to be **typical** or **complete** when all the four whorls are present. When any whorl is absent it is termed **incomplete.**

A flower is described as regular when the members of the whorls are all alike in shape and size.

When the number of members in a whorl is the same or multiple of the number in other whorls, it is described as **isomerous.**

When there are three members in each whorl it is **trimerous,** when there are four **tetramerous** and when there are five **pentamerous.** The flower is said to be **heteromerous** when the number in whorls are different from one another.

In regard to the sex of the flower, it is described as **hermaphrodite** or bi-sexual when both the stamens and pistil are present. It is **unisexual** when either stamen only or pistil only is present. A unisexual flower is termed **staminate** when stamens only are present and **pistillate** when pistil only is present.

In regard to the position of the pistil on the thalamus, the flower is described as **hypogynous** when the thalamus is below the pistil. The latter is placed over the flattened thalamus and the ovary is **superior** in position, e.g., members of the family Malvaceæ, Leguminosæ and Solanaceæ are all with superior ovary. In such a flower, the outer three whorls, viz., calyx, corolla and androecium spring from beneath the ovary. In some flowers, the thalamus forms a deep cup and the ovary is situated at the bottom of the depression and the wall of the ovary fuses with the walls of the cup. The outer three whorls of the flower viz., calyx, corolla and androecium arise from the top of the cup and apparently from the top of the ovary itself. The flower is then said to be **epigynous** and the ovary then is **inferior** as in the members of the family Rubiaceæ, Musaceæ and Compositæ.

In some instances the cup formed by the thalamus may not be deep. The ovary then will be half immersed in the cup with the outer three whorls arising from the margin of the cup. The flower is then described as **perigynous.**

On examining a large number of flowers from different species of plants it will be seen that differences in floral structure are due to considerable variations in the parts of flowers. We shall now consider these variations in detail.

Bracts.

Solitary flowers arise from the axils of ordinary foliage leaves, but flowers spring from the axils of bracts in an inflorescence. Bracts are sometimes called **hypsophylls,** and they vary very much in shape, size and even in colour. These are usually small and scale-like in appearance. In some plants flowers do not have bracts. For instance, in the inflorescence of radish and mustard plants, bracts do not occur. The side of the flower away from the axis and towards the bract is **anterior or dorsal** and the side towards the axis is **posterior** or **ventral.**

Besides the single bract from whose axil the pedicel springs, other bracts usually two in number, occur higher upon the pedicel on the lateral sides of the flower. These are called **bracteoles.** In the flowers of *Dolichos Lablab* and *Clitoria ternatea* bracteoles are clearly seen. When more than two bracts occur in whorls below the calyx, as in the flowers of cotton and *Hibiscus rosa-sinensis*, the whorl is called **epicalyx.** Often the bracts become aggregated at the margins of heads (see figs. 91 & 92) or at the bases of the pedicels in umbels. Then they are said to form an **involucre** and the bracts are **involucral** bracts. Sometimes bracts are very large and cover the whole of the inflorescence, as in many Aroids and palms, and then these are called **spathes.** In Musa there are many large bracts, each enclosing a series of flowers in two rows. There are also bracts that are coloured and then they are said to be **petaloid.** Such bracts occur in *Delonix*, *Bougainvillea* and *Combretum*.

In the grasses, bracts are more prominent than the perianth and they protect the essential organs. The bracts in these plants are termed **glumes** and **lemmas** and the bracteoles as **palea.**

The calyx.

In the flowers of many plants the calyx is found outside or below the corolla, and it is the outermost whorl in a flower bud. The essential organs and the petals, when young, required protection, and this is afforded by the calyx. Generally it is green in colour, but in some plants, as in *Cassia siamea* and *Cæsalpinia pulcherrima* it is coloured just like the petals and then it is described as **petaloid.** In *Musænda* only one sepal is big, prominent, showy and petaloid. There are also flowers in which the calyx does not exist. For instance, the flowers of grasses are without the calyx. In these flowers protection to the essential organs is afforded by the bracts. In Compositæ the calyx is generally modified into pappus (=a cluster of hairs).

The calyx is usually simple and consists of a single whorl, and may be rarely double as in *Tinospora*, *Tiliacora*, *Cocculus* and *Berberis*. The component parts, the calyx or the sepals may be wholly free and then the calyx is described as **polysepalous.** When the sepals cohere by their margins the calyx is **mono** or **gamosepalous.** The degree of union may be to a very small extent at the base as in *Solanum*, or it may be throughout its margin so as to form a regular tube as in *Datura*, and we may have also gradations between these two extremes. Sepals may be prolonged at their backs into spurs, as in *Viola*. When the sepals are similar

in shape and size, the calyx is **regular**, and it is **irregular** if the sepals are not alike as in *Ocimum* and *Leucas*.

In the flowers that have expanded and opened the sepals and the petals may be present, but they fall after flowering and then they are said to be **deciduous.** It is not unusual for the sepals and petals to fall off as soon as the flowers begin to expand and open, and then they are said to be **caducous.** The sepals in the flowers of Poppy and *Argemone* are caducous. In some flowers the calyx persists without falling off, and then it is **persistent.** Often as in many *Solanums*, the calyx grows with the fruit and then it is said to be **accrescent.** The inflated calyx of *Physalis* is a good example of an accrescent calyx.

The Corolla.

Next above the calyx and immediately inner to it lies the corolla. Its members or the petals generally alternate with the sepals. The corolla is either simple consisting of only one whorl of petals, as in *Tribulus*, or it may have two whorls of petals as in *Argemone*. There are also flowers wherein the petals are many, as in *Nymphæa* and *Nelumbium*. In a flower the corolla is the most conspicuous and attractive part and it is usually coloured. The corolla varies more than the calyx. The petals may be free, as in *Tribulus*, *Hibiscus* and *Anona* and then the corolla is said to be **polypetalous.** If, on the other hand, the petals cohere by their margins, as in *Datura*, *Ruellia* and *Ipomœa* the corolla is **mono** or **gamopetalous.** The terms **choripetalous** and **sympetalous** are sometimes used instead of polypetalous and gamopetalous respectively.

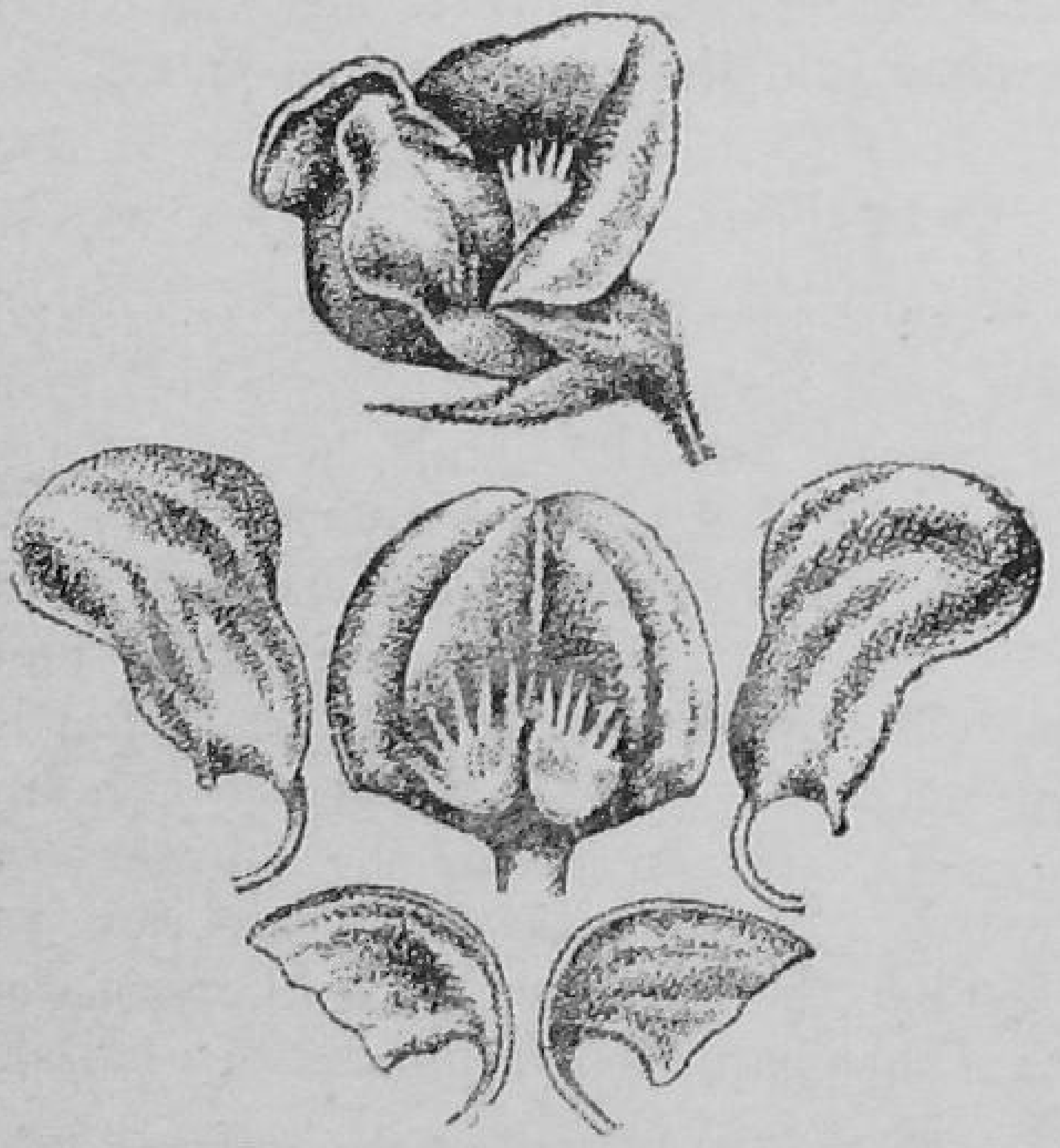


Fig. 97. Papilionaceous flower.

Polypetalous Corolla.—The polypetalous corolla is generally very regular in most flowers. In the plants belonging to the

family Cruciferеæ there are four regular petals arranged in the form of a cross. They are described as **cruciferous** petals.

In some flowers it is irregular. For instance, the flowers in the family Papilionaceæ have in them petals that are not all alike. The flower presents a definite pattern and it is divisible into two similar halves only in one plane and therefore, it is said to be **zygomorphic** or bilaterally symmetrical. One of the five petals placed next to the axis is larger than the others and it is termed the standard. It encloses the remaining four petals in the bud. Of these, two lying one on each side, just below the standard, are alike in shape and size. This pair constitutes the **alæ** or **wing petals.** The remaining two anterior petals adhering by their lower margins are called **keel petals** or **carina.** (Fig. 97.)

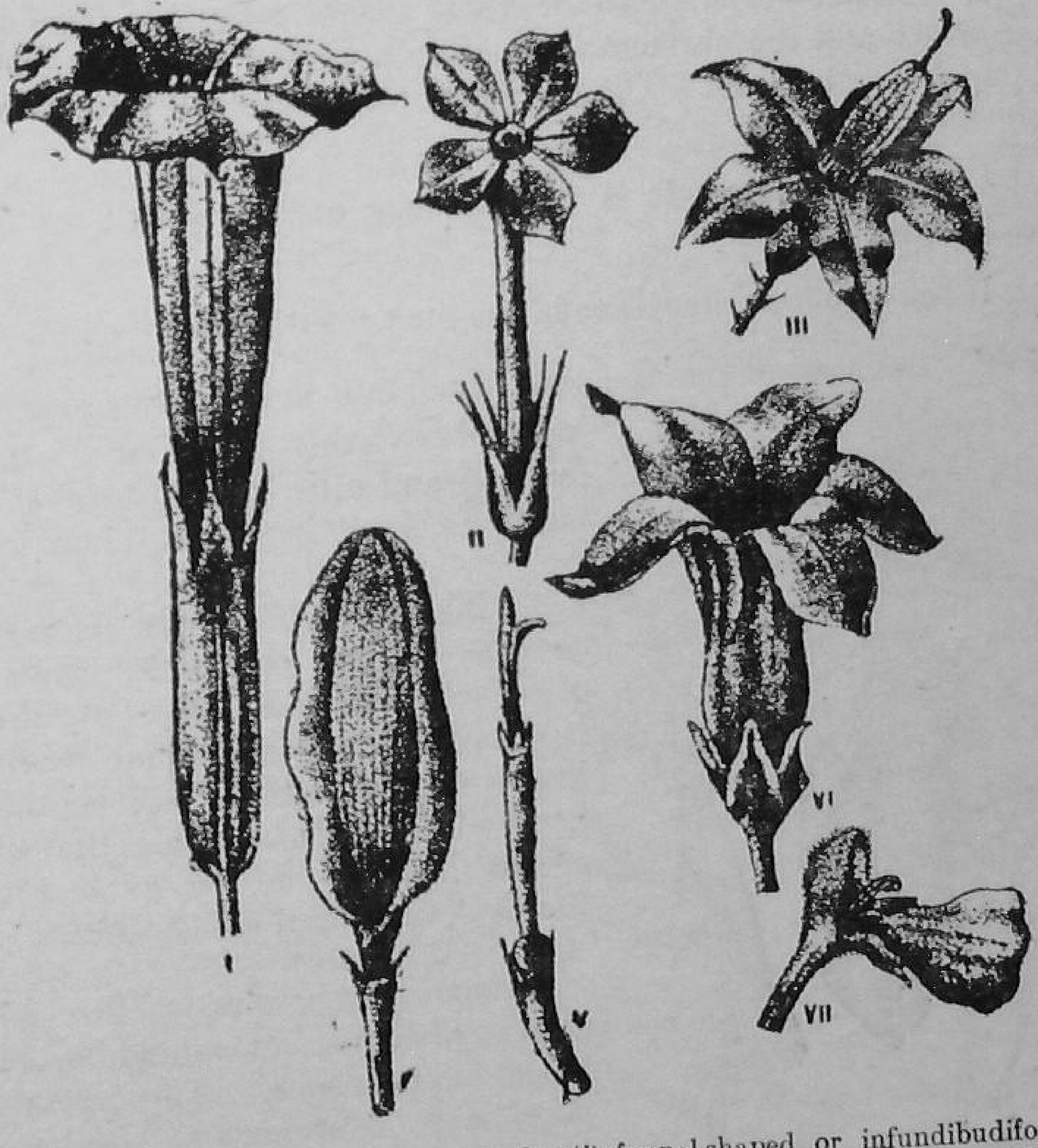


Fig. 98. Forms of gamopetalous corolla : (i) funnel shaped or infundibudiform (ii) salver shaped (iii) rotate (iv) ligulate (v) tubular (vi) campanulate (vii) labiate.

Gamopetalous Corolla.—In a gamopetalous corolla we can distinguish two parts namely, the upper portion or the **limb** and the lower united part or the **tube.** The top of the tube is termed the **throat.**

The form or shape of gamopetalous corolla is varying in different plants. It may be regular or irregular. The following are a few important types (Fig. 98).

1. **Funnel shaped.**—The corolla is said to be **funnel shaped** or **infundibuliform** when the tube insensibly widens upwards as in *Datura*.

2. **Salver-shaped.**—It is described as salver shaped or **hypocrateriform** when the straight and long tube abruptly ends in a flat spreading limb as in *Lochnera*.

3. **Rotate.**—It is rotate or **wheel shaped** when the tube is suppressed and the segments are horizontal and divergent like the spokes of a wheel. The corolla is rotate in some species of *Solanum*.

4.—**Campanulate.**—It is campanulate or bell shaped as in *Stenolobium*.

If the corolla is irregular and the limb cut it is described as:—

1. **Labiate.**—When the limb is cut into two principal superimposed divisions called lips, e.g., *Ocimum* and other members of the family Labiate. It is termed labiate.

Fig. 99. Spadix of *Musa*.

2. **Ligulate.**—When the corolla consists of five confluent petals, of which two join only at the base and unite throughout their length with the three others and hence strap shaped. This kind of corolla is found in the outer ray florets of sunflower, and *Tridax*.

Corona.—The corolla, whether the petals are free or united, often bears appendages. The petals may have a nectary at the base of each petal, as in *Ranunculus* or they may bear scales as

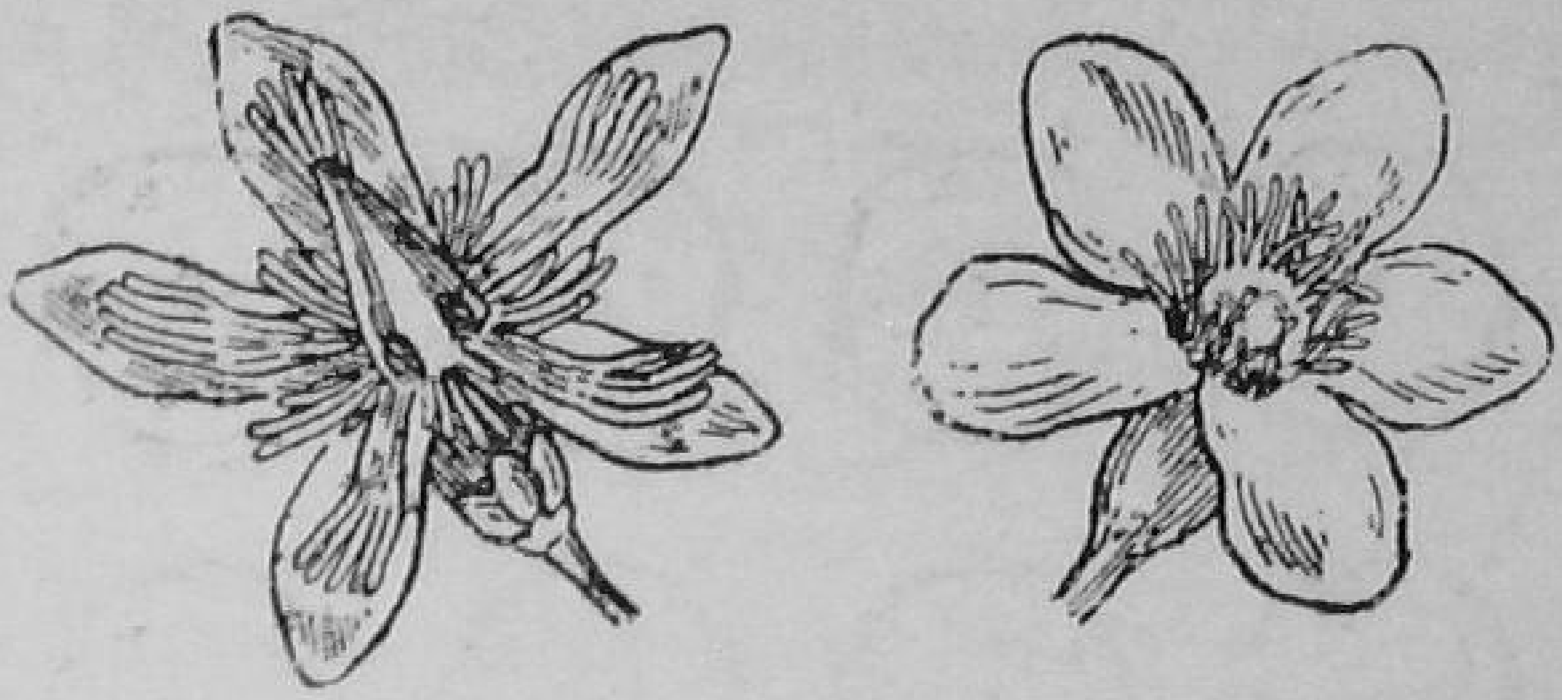


Fig. 99. Coronas of Corolla. (1) *Wrightia*, (2) *Nerium*.

in *Lepisanthes*, *Sapindus* and *Cardiospermum*. In monopetalous corollas the throat often bears numerous hairs as in *Thevetia*. In *Wrightia* the corolla has fimbriate scales united at the base in a ring. In the throat of the corolla of *Nerium* we find a crown of long filamentous processes. These appendages are called **corona.** (Fig. 100.)

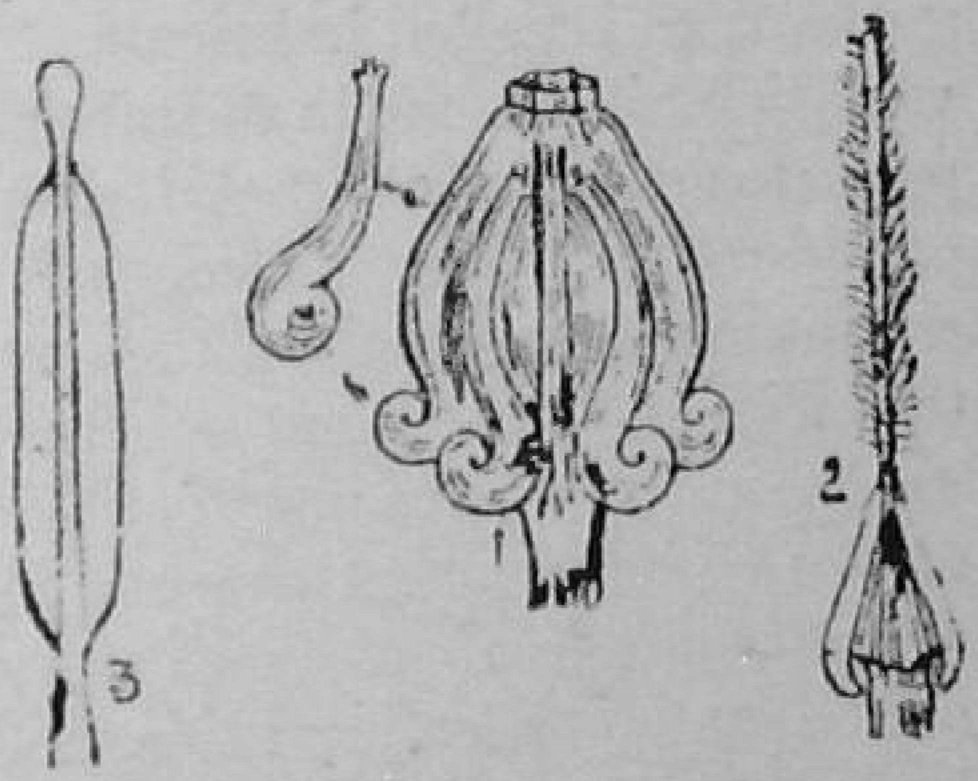


Fig. 101. Staminal Coronas. (1) *Calotropis*, (2) *Nerium*, (3) *Nelumbium*.

Aestivation.—The sepals and petals protect the stamens and the pistil in the bud and therefore, they remain folded in the bud. This folding or œstivation is of interest, because it is uniform and common to groups of plants or families. For instance, the petals of *Calotropis gigantea* touch each other by their margins and this mode of folding is **valvate**. The petals are said to be **contorted** or **twisted** when the front margin of petal lies above the hinder margin of the petal before it and its hinder edge is covered by the front margin of the petal behind. In this kind of folding every petal has one of its edges covered and the other covering. The petals may be contorted to the right or the left. (See fig. 102). Instead of this overlapping of the edges being

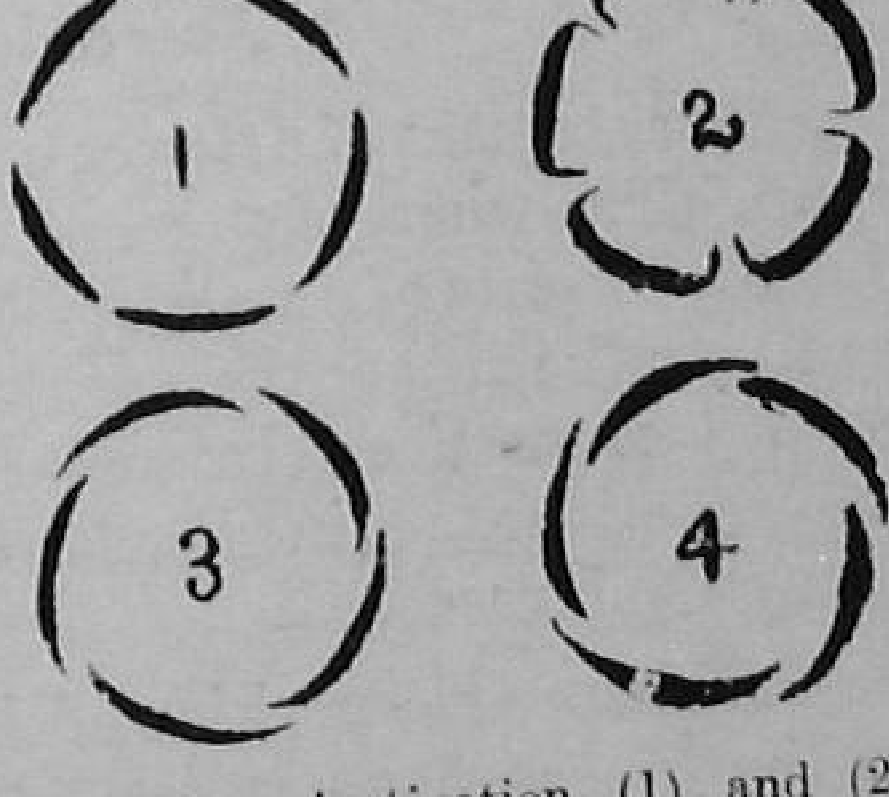


Fig. 102. Aestivation (1) and (2) valvate, (3) and (4) contorte or twisted.

regular, it is disturbed in some flowers. Of the five petals one or two often get pushed in or out completely, so that both the edges

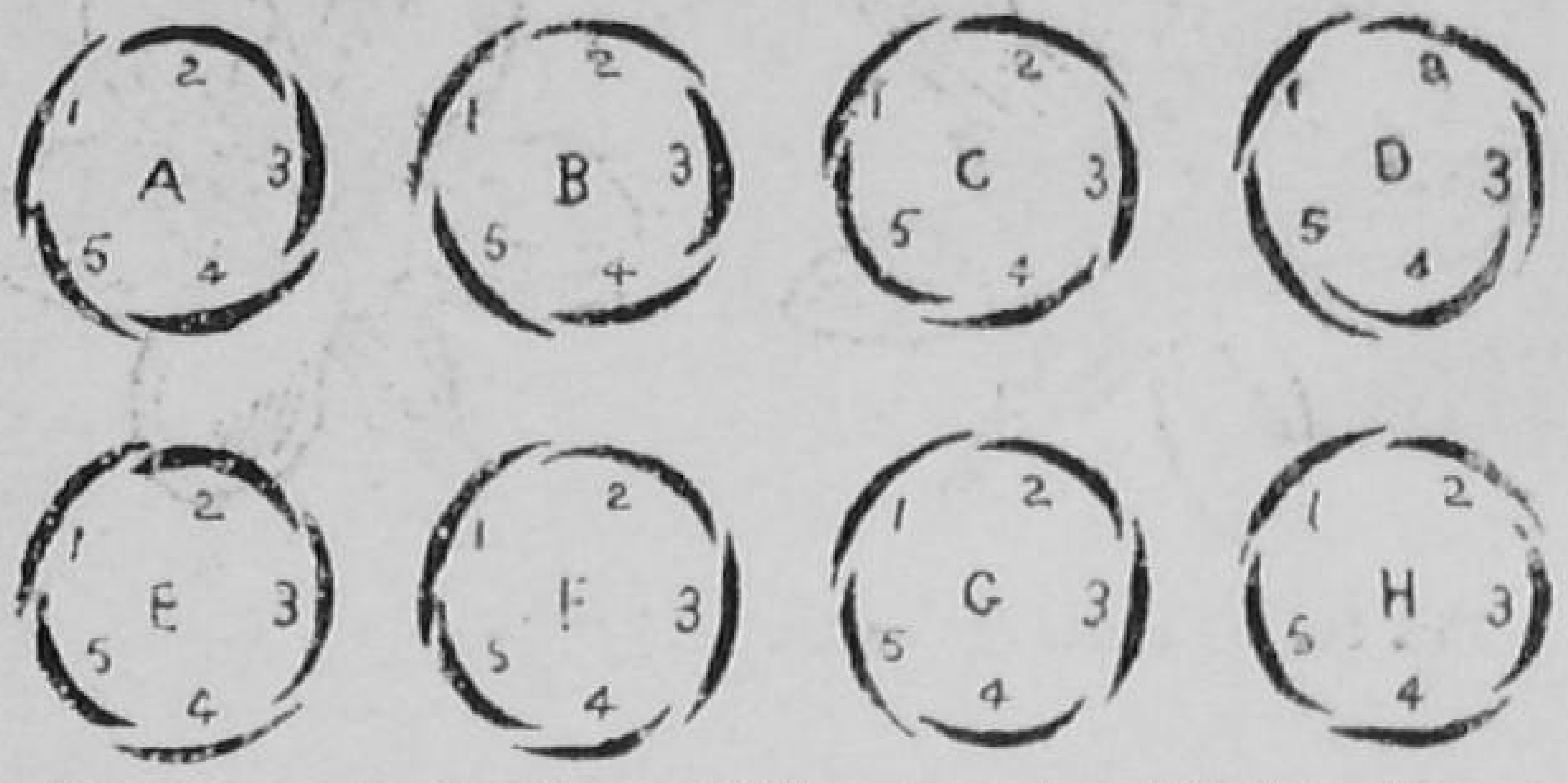


Fig. 103. Aestivation. Different modes of imbrication.

of the members thus disturbed are in or out. This mode of æstivation is called **imbricate.** If we take into consideration the variations in the mode of imbrications we get forty modes. If we pay attention to one petal assuming that both its margins are outside and then consider all possible ways of folding of the remaining four petals, there are eight possible ways of folding (See Fig. 103). As there are five petals the possible mode of æstivation in the case of imbrication becomes forty. Of these different modes of imbrication the one in which two petals or sepals are outside completely and two consequently inside, with one in and out is noteworthy, and this mode is known as **quincuncial** (See Fig. 103 E to H). The sepals of *Ipomœa* are quincuncial. In connection with æstivation we have assumed that flowers are **pentamerous** in their enveloping organs, and this is so in the vast majority of plants. However, in some plants the flowers have three or four members in their perianth whorls. So the flowers may also be tri-or-tetramerous.

Andrœcium or Stamens.

The stamens of a flower are collectively known as the **androecium.** The whorl of stamens may be single, double or more. A stamen consists of a stalk or filament bearing an anther at its free end. In the anther there are two lobes held together by the tissue termed **connective.** In some flowers the anther may consist of only one lobe, as in the flowers of the plants belonging to the family Malavceae.

Position.—The position of the stamens on the floral axis relative to the other whorls varies. When the stamens spring from the thalamus below the base of the pistil, as in *Tribulus,* they are **hypogynous.** They are **perigynous** when the insertion is on the

edge of the thalamus round and above the base of the ovary as in the flowers of Peach, Rose and Pomegranate. When we find them inserted on the top of the ovary it is **epigynous.**

Number.—In some flowers the stamens are equal in number to the petals, as in *Ipomœa* and then the flower is **haplostemonous.** If the stamens are twice as many as the petals, then the flower is **diplostemonous.** We speak of the stamens as **indefinite** when there are more than twenty in a flower.

Length.—The stamens are not always equal in length. For instance, the stamens in the outer whorl in *Tribulus* are shorter than those of the inner whorl. In the flowers of *Linum*, *Oxalis* and *Biophytum* five stamens are long and five are short. In some species of *Ipomœa* the five stamens are of unequal lengths. The

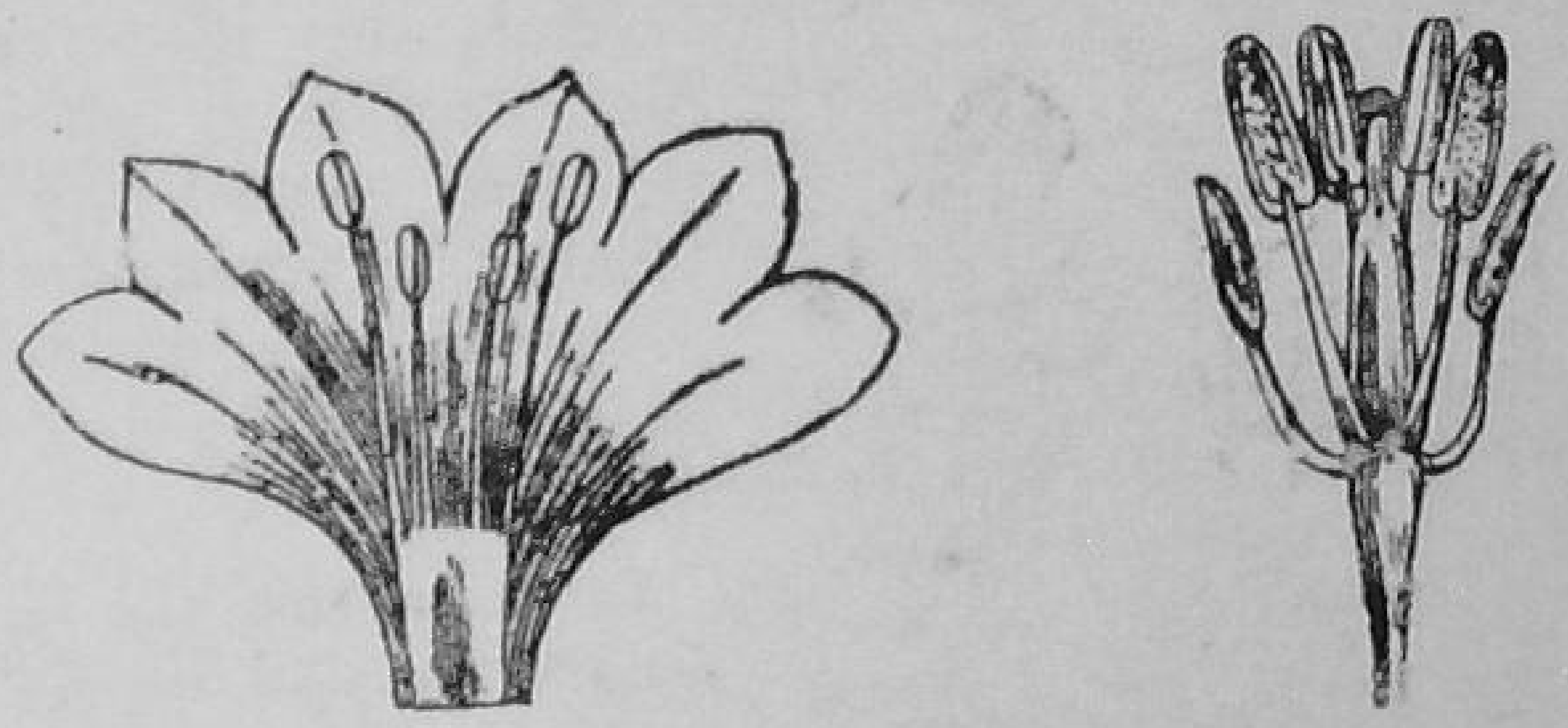


Fig. 104. Didydamous and tetradynamous stamens.

flowers of mustard and radish have six stamens of which two are short and opposite to one another, and four long placed in opposite pairs, and so the stamens are said to be **tetradynamous**. They are **didynamous** when there are four of which two are long and two are short. (Fig. 104.) As examples we may, mention the flowers of *Leucas, Tecoma and Ruellia.*

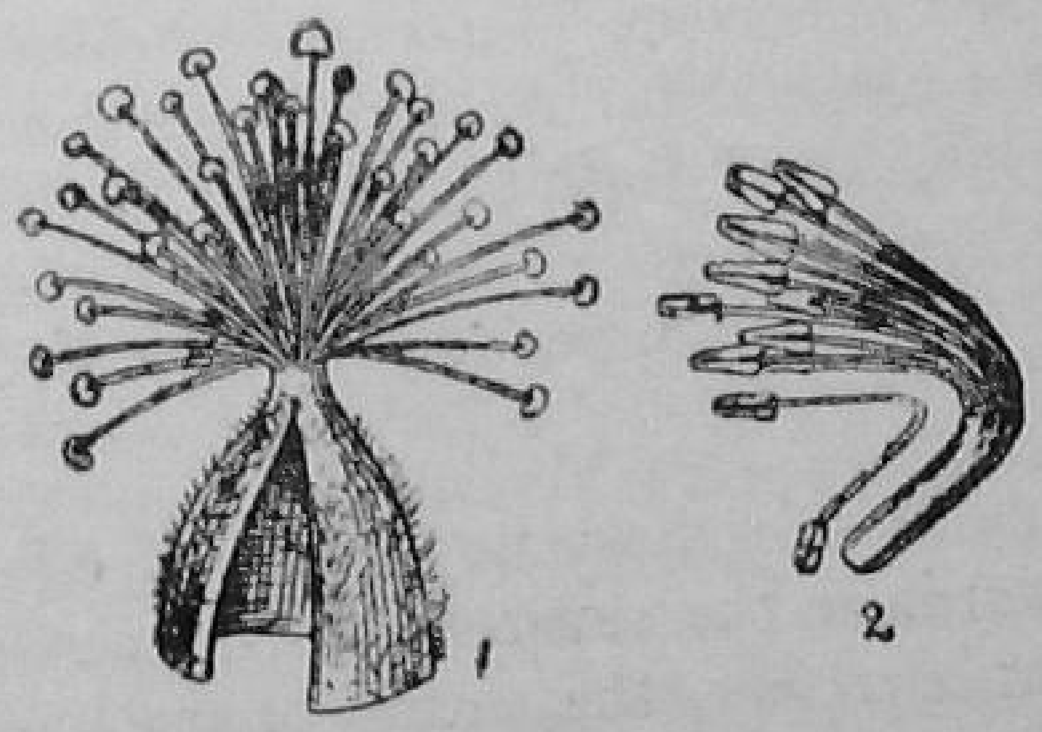


Fig. 105. Mon- and di-adelphous stamens. (1) *Abutilon*. (2) *Crotalaria.*

Cohesion.—In most flowers the stamens are completely independent of each other as in *Tribulus* and then they are said to be **free.** However, in some flowers the filaments are more or less united in a single tube as in *Hibiscus vitifolious* and *Abutilon indicum* and then the stamens are **mon-adelphous.** (Fig. 105). When united into two bundles as in

Sesbania grandiflora and *Tephrosia villosa* they are **di-adelphous.** (Fig. 105). If the anthers cohere the filaments being free, the stamens as are **syngenesious**. (Fig. 106). Such stamens occur in *Lobelia*, in all the flowers of the family Compositae and in the flowers of gourds and melons. The stamens are **gynandrous** if they are attached to the pistil, as in the flowers of *Aristolochia* and orchids.

Fixation.—The anthers usually consist of two lobes, the lobes being held together by the connective, which is only a prolongation of the filament. As the connective varies very much in size and shape, the anthers present variations in their appearance and in the disposition of the lobes. In some flowers the anthers are attached to the filaments, each by its base and then the anther is **basifixed.** It is **dorsifixed** when attached by the back, and **versatile** when it moves freely, the anther being attached to the finely pointed end of the filament. It is **adnate** when the connective runs up from base to the top of the back side of the anther lobe.

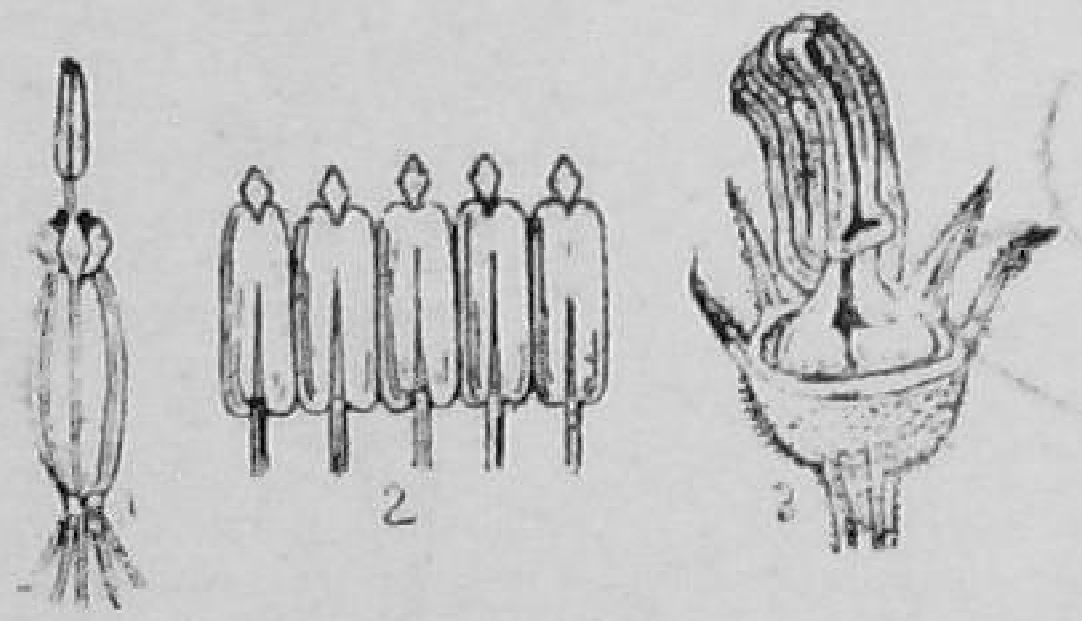


Fig. 106. Syngenesious anthers. (1) and (2) *Tridax procumbens*. (3) *Cucurbita maxima*.

In an anther the lobes are usually parallel, as in *Datura*, *Solanum* and *Cassia*, but occasionally one lobe is inserted on the connective a little above the other, as in *Justicia*. Sometimes the connective is so short and small that the anthers are held together by a mere point. In some flowers the anther lobes diverge, being attached to the connective at one point. The connective is elongated into two unequal arms, and the longer one bears an anther and the other one may have a rudimentary anther or none. Occasionally the short arm may be absent. Such stamens are found in the flowers of *Ocimum* and *Salvia*. It is not unusual to find the connectives prolonged beyond the anther lobes and forming glands, scales or tails as in *Neptunia*, *Ionidium* and *Nerium*. The filaments also have appendages in *Calotropis*. All these appendages are called staminal **corona**.

Dehiscence.—The anthers dehisce in most flowers longitudinally either from above downwards or the reverse. In *Solanum* they open by apical **pores** ; that is to say, the suture opens just at the top. We also have anthers opening by means of **valves** as may be seen in the flowers of *Mahonia*, *Berberis* and in those of the

family *Laurineae*. The longitudinal slit may be directed towards the centre of the flower and then dehiscence is **introrse** ; it may be towards the petal and then it is **extrorse.** Often the opening is lateral. **Horizontal** and **circular** dehiscence of anthers are not uncommon. When the dehiscence is along the length of the anther lobes it is termed **longitudinal** as in *Datura* ; when it is breadth wise in the anther lobe it is termed transverse as in Labiatae.

Gynoecium or the Pistil.

Carpels.—The gynoecium crowns the thalamus and occupies the centre of the flower. The component parts of the pistil are called **carpels** and they vary in number. In plants of the family Leguminosae the pistil consists of only one carpel and hence it is **monocarpellary.** Pistils having more than one carpel are **polycarpellary.** When the carpels are more than one in pistil, they may be free without cohering as in *Ranunculus*, *Thalictrum*, *Polyalthia* and *Bryophyllum*. In this case the pistil is termed **apocarpous.** Fig. (107). The carpels become united into a single body in most cases, and then the pistil is described **syncarpous.** The ovaries alone are united in *Linum*, and the union extends to the top up to the stigma in *Tribulus*, *Ipomoea* and *Solanum*. In *Calotropis* the stigmas and the upper portion of the styles are united, the ovaries being free.

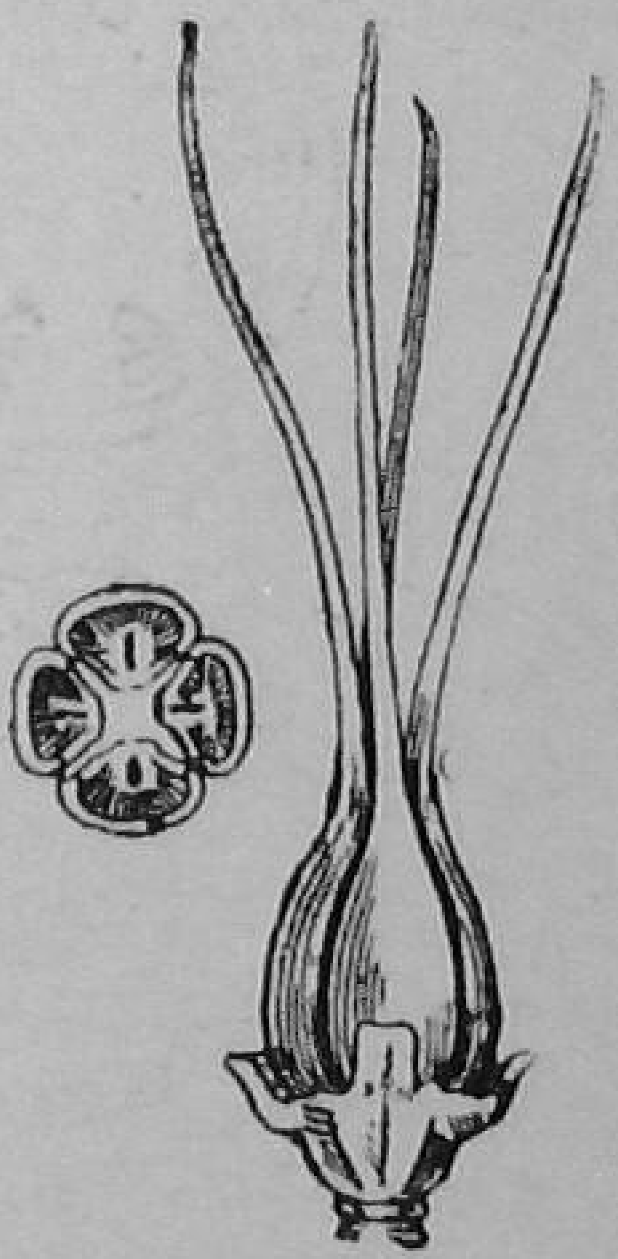


Fig. 107 Apocarpons ovary of *Bryophyllum*.

Suture.—When pistils consist of a single carpel only, as in *Crotalaria verrucosa* and *Dolichos Lablab*, the edges of the carpel are folded and united, and this edge becomes thickened and bears ovules. The thickened edge is called the **placenta**, and in this case it is really double, which becomes obvious when the pistil is opened and then it splits into two partially seed bearing placentas. The suture bearing the ovules is termed the **ventral** and the opposite one is called the **dorsal** suture. When the pistil consists of more than one carpel, the edges of the carpels are folded inwards and become united variously. The disposition of the placentas, termed **placentation,** will also be different depending upon the mode of union of the carpels. (See Fig. 108.)

Placentation.—(i) **Parietal.**—The syncarpous ovary is the result of the union of the carpels of the ovary, and this union may take place in two ways. The edges of the carpels meet at the ends and unite and in this case, whatever may be the number of carpels, there will be only one chamber, but the number of placentas will be the same as the number of carpels. It must be remembered that each of the complete placentas belong to two contiguous carpels, one half of each. The union takes place also by the edges folding inwards so as to form vertical partitions, each composed of two confluent plates called septa belonging to different carpels. In this case the ovary will have as many chambers as there are

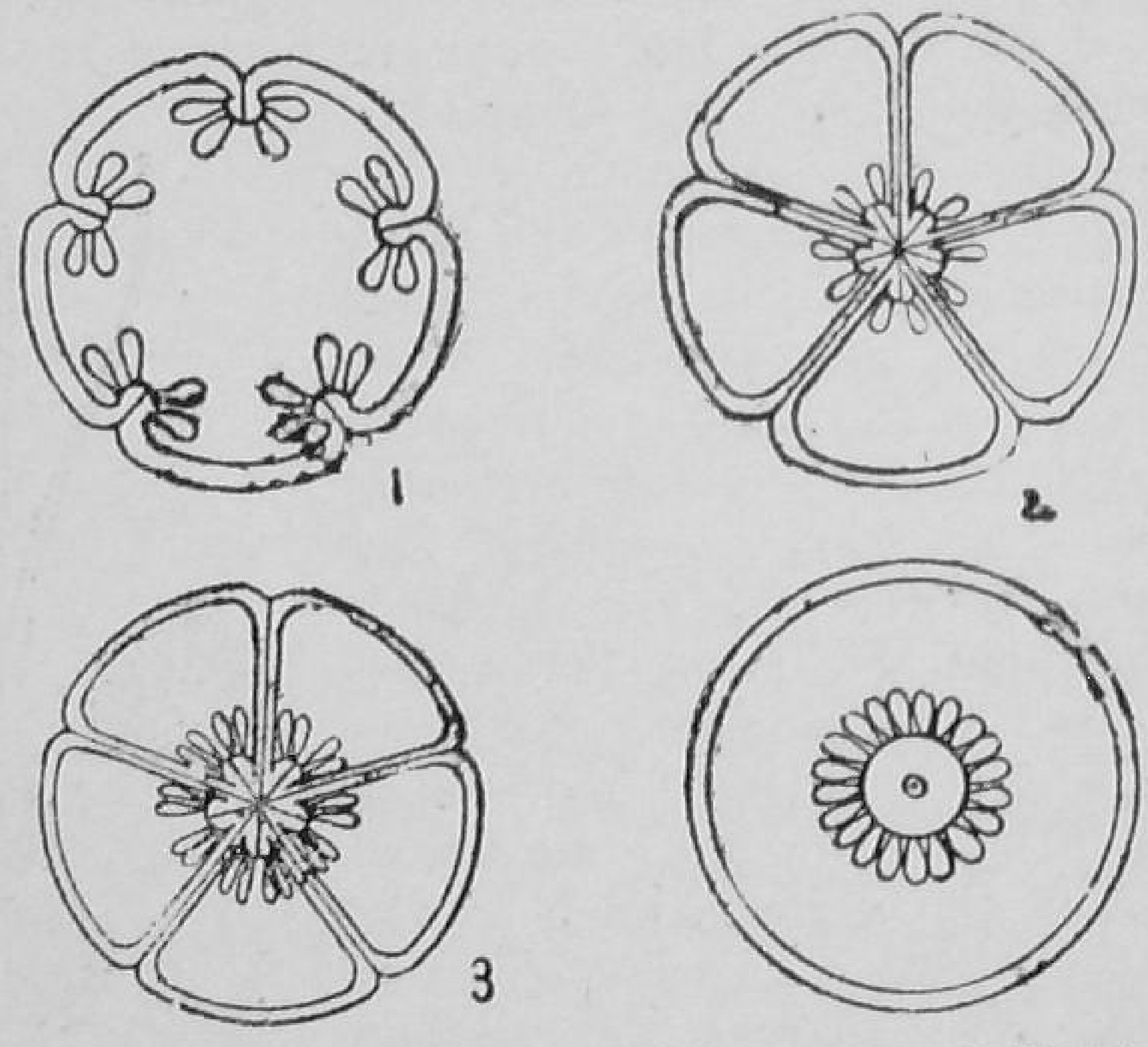


Fig. 108. Different modes of Placentation. (1) Parietal (2) and (3) axile (4) free-central.

carpels. Generally the number of carpels in syncarpous pistil is inferred by the number of stigmas or the styles when they are free, or by the number of placentas. For instance, the ovary of *Ionidium* consists of three carpels, as there are three placentas, although there is only one chamber. As the edges of the carpels touch and unite, the placentas are found on the wall of the ovary and this placentation is called **parietal placentation.** In the ovary of *Argemone* there is only one chamber bounded by its wall or the pericarp, but there are four or five placentas. Hence the ovary is four or five carpelled.

(ii) **Axile.**—In an ovary in which the margins of the carpels project into the ovary and divide it into chambers the placentation is **axile.**

(iii) **Free central.**—The whole of the placenta in a chamber belongs to the carpels which form the chamber because the margins that meet at the centre belong to the same carpels. We have in some ovaries a free central axis, not connected with the pericarp by partitions, bearing the placentas. The ovules are attached all round the free-central axis and, therefore, this is called **free central** placentation.

(iv) **Pendulous.**—When there are only a few ovules, they may be pendulous, as in *Terminalia* and *Quisqualis*.

(v). **Basal.**—Erect single ovule at the base of the single loculed ovary is termed basal e.g., *Celosia* and *Polygonum*.

Position of ovary.—The ovary is termed superior when it is above the other whorls in the flower and not adherent to any of the neighbouring parts. It is **inferior**, if it is placed, apparently below the stamens, corolla and calyx.

Style.—In an apocarpous pistil, each carpel is prolonged above into a style ending in a stigma, and when the pistil is completely syncarpous it has only one style and stigma. The style usually springs from the top of the ovary and then it is terminal. It may be lateral, as in the pistil of the jack tree.

The style is said to be **gynobasic** when the base of the style is somewhat dilated and extends below ovaries, as in *Ocimum*, *Anisomeles* and *Leucas*. Sometimes the style is branched at the free end as in *Abutilon* and *Hibiscus*.

The Thalamus or Torus.—The thalamus is the apex of the pedicel situated between the calyx and the gynaeceum on which the corolla and stamens are inserted. Besides bearing the stamens and petals, the thalamus produces in some flowers glands. In many plants the torus develops an annular ring or a disk as in *Ipomoea*, *Crotalaria* and *Dolichos*. It usually secretes honey and so it is a nectary.

As a rule in primitive types of flowers, the thalamus is somewhat round or conical and bears all the whorls without much interspace. For instance, in *Ranunculus*, *Tribulus* and *Argemone*, the thalamus is only a rounded body. Occasionally the floral axis becomes elongated so that there is interspace between the series of parts. In *Gynandropsis pentaphylla* the pistil and the stamens are carried up a considerable distance above the sepals and petals. This elongated part of the thalamus or the floral axis is called **gynandrophore,** or a stalk bearing the gynæceum and the andrœcium. In species of *Capparis* and *Cadaba* the pistil alone is raised on an elongated axis. This elongated stalk of the ovary is called

gynophore. Frequently, the thalamus widens out and forms a flat structure or a broad or narrow cup. For instance, in the sunflower the receptacle of the whole inflorescene becomes a flat disk. In the flowers of *Zizyphus* the thalamus forms a shallow cup and the ovary also gets immersed in an annular lobed disk which is an outgrowth of the thalamus. The shallow cup from the bottom of which the pistil arises in the flowers of *Caesalpinia* and *Cassia* is thalamus hollowed out. When the thalamus forms an open flat plate or a cup the stamens, petals and the sepals are borne by the edge of the expanded thalamus. The position of the pistil however is not affected. It still maintains its usual position, that is to say, it remains in the centre of the flower and on the top of the thalamus. As examples of flowers in which the thalamus is cup shaped we may mention the flowers of Peach, Rose and Pomegranate. When the torus is flattened or cup shaped the sepals, petals and the stamens are inserted round the edge of the thalamus. Hence they are not underneath the gynæceum, but round about it. This gives rise to the perigynous condition. In this condition the carpels are partially adherent. They are free in the Peach and Rose and partly adherent in the pomegranate. A more important modification is that in which the thalamus is cup shaped leading to the sinking of the gynæceum downwards into the tissue of the hollowed out thalamus. In this case the inner-surface of the thalamus cup fuses with the outer surface of the pericarp. This results in the epigynous condition with inferior ovary (Fig. 109.)

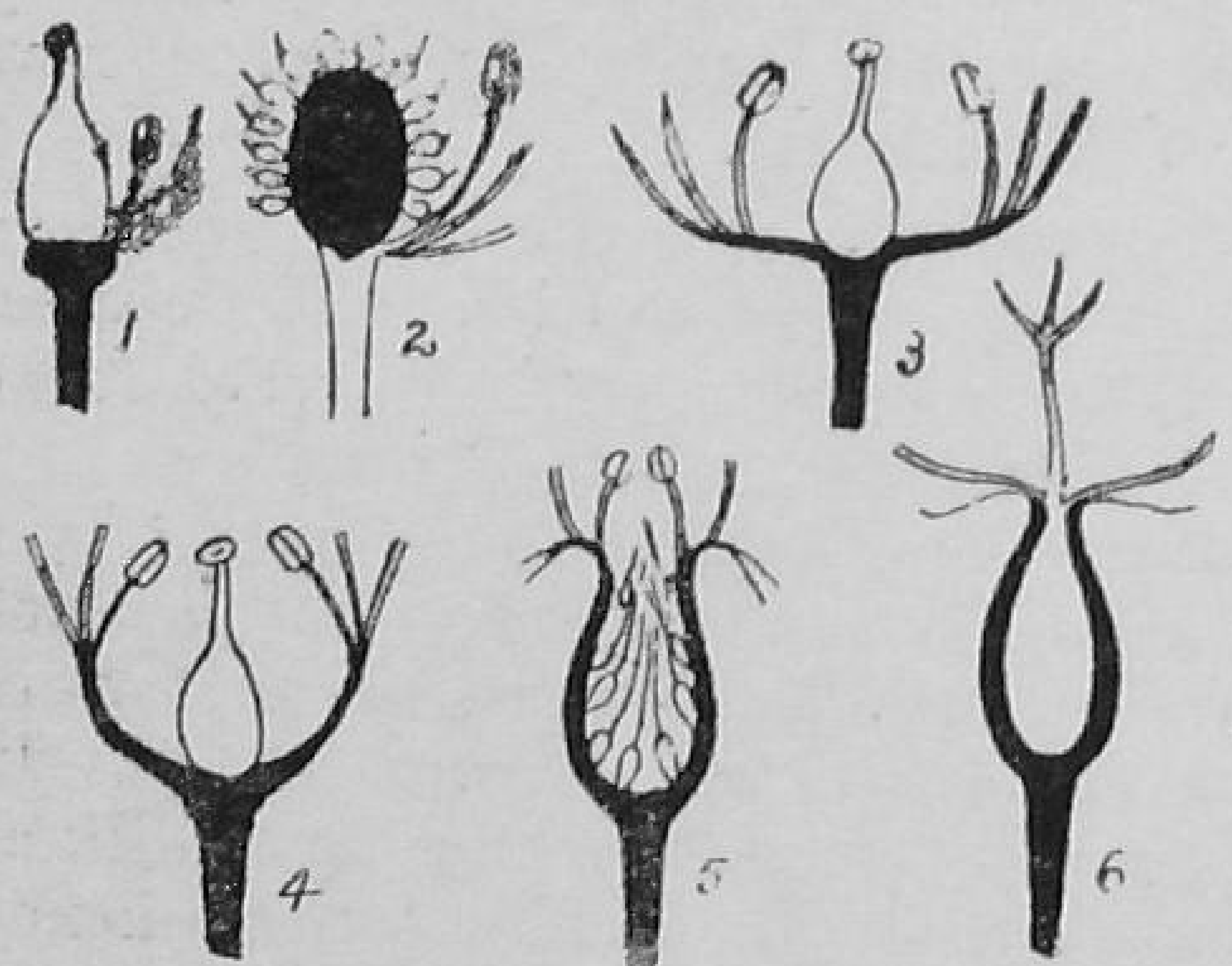


Fig. 109. Modifications of the thalamus. (1) ordinary type (2) swollen thalamus (3) disk shaped thalamus (4) and (5) hollow thalamus. (6) hollow and fused thalamus.

Whorl.—As has already been remarked in a typical Angiospermic flower the parts are arranged in five alternating whorls, of which two form the perianth, two the stamens, while the gynæceum consists of one whorl. The flower is pentacyclic because it has five cycles. It is pentamerous as it has five members in each whorl in most dicotyledons, and trimerous as it has three

members in each in monocotyledons. The number of members in each whorl is either the same, or there is an increase or decrease, especially in the andrœcium and the gynæceum. The significance of this decrease or increase will be referred to later on.

Sex.—Flowers may have both the essential organs in the same flowers, as in *Tribulus* or they may be found on different flowers, as in *Cucurbita* and *Coccinea.* In the former case the flowers are **bisexual** or **hermaphrodite** and in the latter **unisexual** or **diclinous.** A unisexual flower is **staminate** or male if only stamens are present. When it bears the pistil only it is a female or

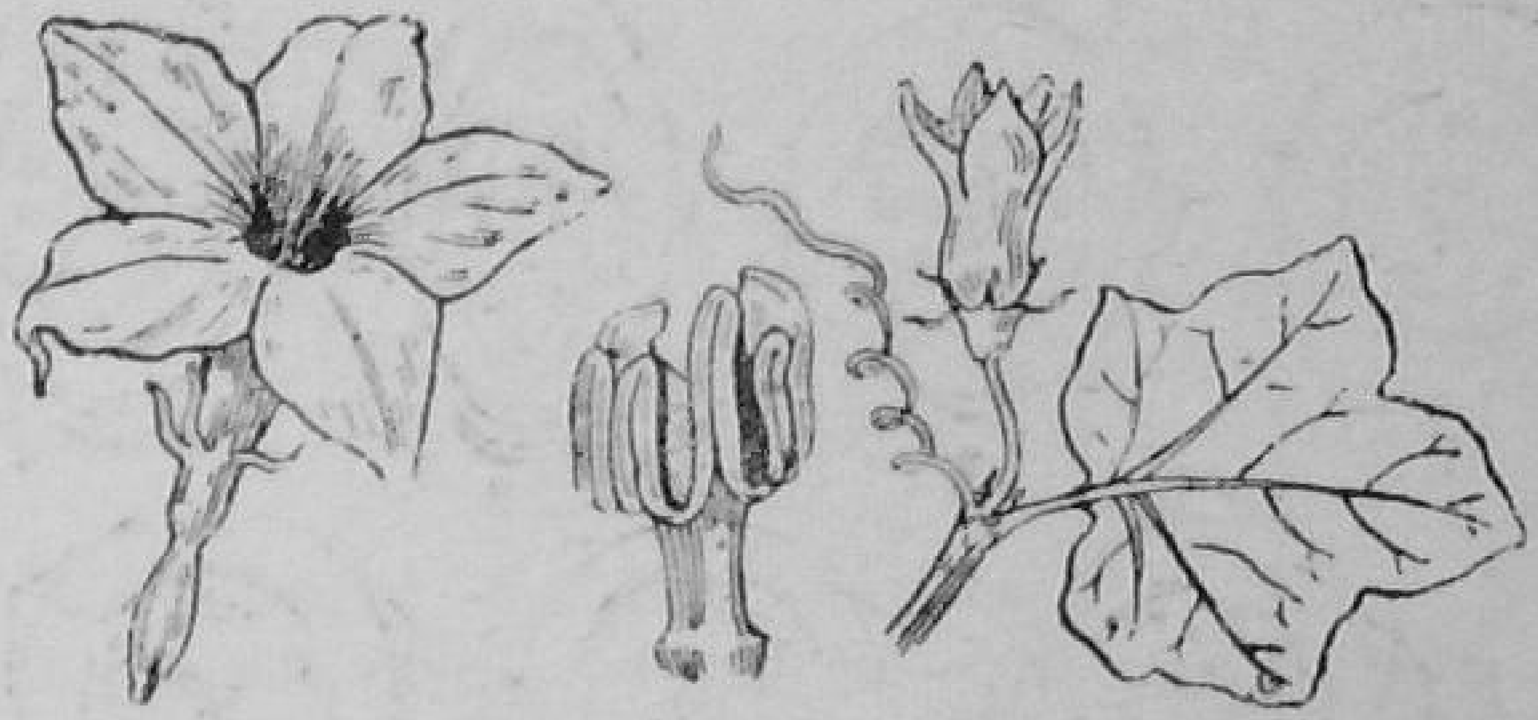


Fig. 110. Unisexnal flowers of *Coccinea indica* (a dioecions creeper).

pistillate flower. When flowers are dicilinous both the staminate and pistillate flower may be present on the same plant as in *Cucurbita* and then the plant is said to be **monœcious.** If the pistillate and staminate flowers are borne by different individuals, as in *Coccinea* then the plant is **diœcious.** (Fig. 110) Sometimes we may have hermaphrodite and unisexual flowers occurring on the same plant and such plants are **polygamous.**

Floral Diagrams.

To learn the parts of a flower and their disposition in it, we should examine not only the flower but also a flower bud · If we take a transverse section of a bud, we see not only their parts but also their arrangements with reference to one another (see Fig. 111).

It is usual to represent these sections in a diagrammatic manner, and such diagrams are called floral diagrams. This is a most convenient method for showing clearly the positions of the various parts of the flower. The floral diagram is made up of a number of concentric circles corresponding to the number of whorls. On them the positions as well as the union of the parts of each whorl are shown. The position of the floral axis and that of the bract are also indicated in the diagram (See Fig. 111).

Floral formula.—It is also usual to show the position and arrangement of parts of a flower by a **floral formula.** This gives a very brief expression for the parts as shown in a floral diagram. The calyx, corolla, andrœcium and gynæceum are represented by the letters, **K, C, A** and **G,** respectively. The number of members in each whorl is placed after the letter. The cohesion of the members of a whorl is shown by enclosing the proper number within ordinary brackets, thus **C** (**5**) which means a monopetalous corolla of five petals. Two whorls of the same kind are

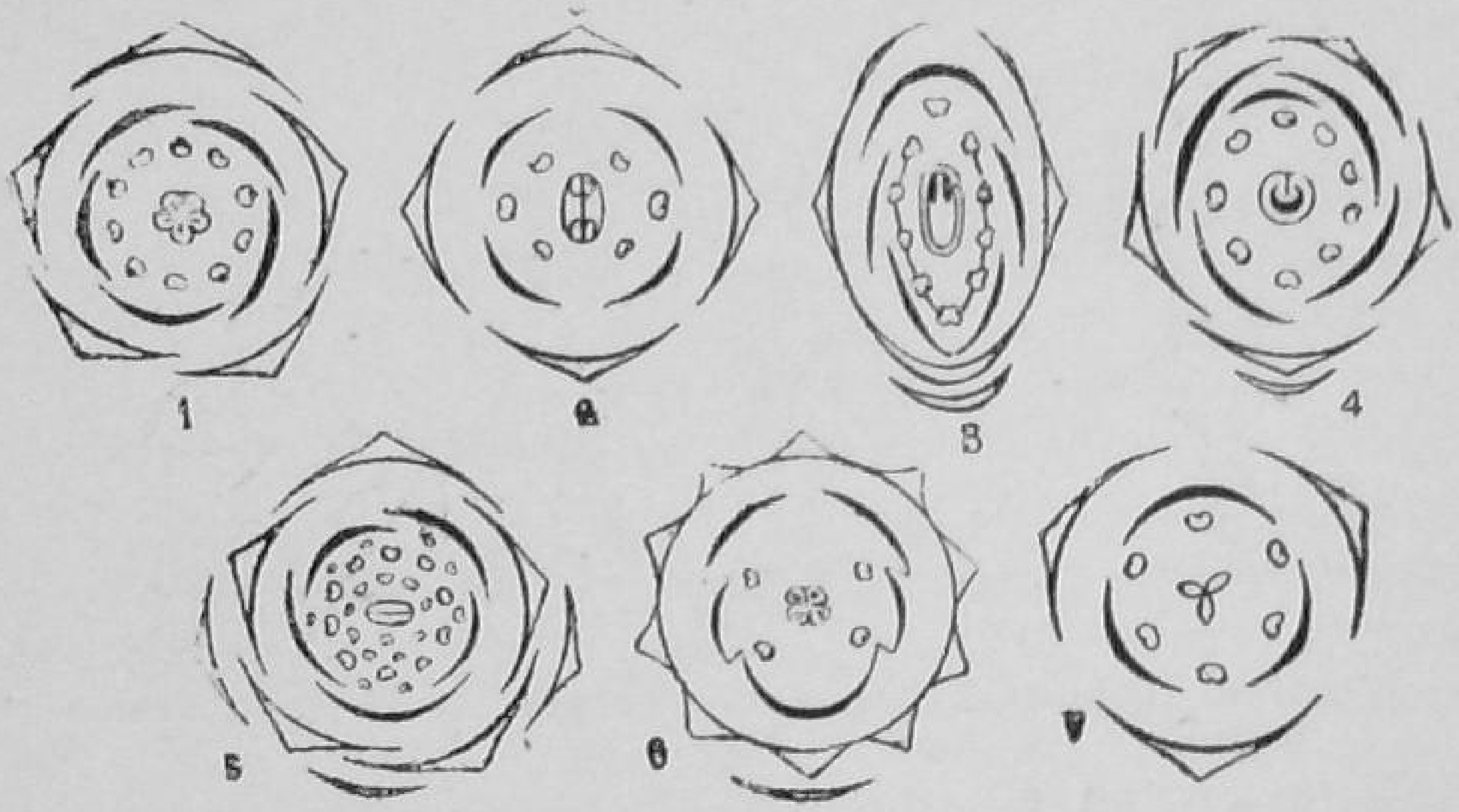


Fig. 111 Floral diagrams. (1) *Tribulus.* (2) Radish. (3) *Dolichos.* (4) *caesalpinia.* (5) Guava. (6) *Leucas.* (7) monocotyledon.

represented by repeating the number with a plus sign between. When there is a large number of members in any of the whorls, it is denoted by the symbol ∞. The superior or inferior position of the ovary is indicated by placing a horizontal line below or above the number representing the carpels respectively. The floral diagram given in fig. 111 may be expressed by floral fomulæ as shown below :—

Tribulus ..	—**K** 5	**C** 5	**A** 5+5	$\underline{G}$ (5)
Radish ..	—**K** 2+2	**C** 4	**A** 2+4	$\underline{G}$ (2)
Dolichos ..	—**K** (5)	**C** 5	**A** 1+(9)	$\underline{G}$ 1
Cæsalpinia ..	—**K** 5	**C** 5	**A** 10	$\underline{G}$ 1
Guava ..	—**K** 5	**C** 5	**A** ∞	$\underline{G}$ (2)
Leucas ..	—**K** (5)	**C** (5)	**A** 4	$\underline{G}$ (2)
Lily ..	—**K** 3	**C** (3)	**A** 3+3	$\underline{G}$ (3)

CHAPTER IX

FLOWER-THE ESSENTIAL ORGANS AND THEIR FUNCTIONS

Although the function of the flower is the production of seeds, the parts of the flower directly concerned in this work are the essential organs, **androecium** and the **gynoecium**. The formation of the seed involves two distinct processes, namely, **pollination** and **fertilisation.** The conveyance of the pollen-grains from the anther to the stigma or the receptive surface at the distal end of the gynœcium is **pollination.** As soon as the pollen grain reaches the stigma it germinates, forms a pollen tube, which penertrates the style and reaches the ovule. A bit of specialised protoplasm with a nucleus, the male gamete passes from the pollen tube into the interior of the ovule. Within the ovule and in the embryo-sac a nucleus is specialised as the **egg cell** or **ovum,** the female gamete, and with this the nucleus from the pollen tube fuses. This fusion of the two nuclei from two distinct sources is **fertilisation**. After this, the fertilised cell now called the **zygote,** the resultant of the fusion, divides and develops into the **seed.**

Stamens.

Stamens are the organs that produce the pollen grains. We already know that pollen is formed within the anthers. An anther is two lobed and the lobes are attached laterally to the connective, through which a vascular bundle runs. The stamens of *Tribulus terrestris* may be studied for its structure, as it is typical of the anthers of a large number of plants. When young, each of the two anther lobes will have two locules or **pollen sacs,** full of pollen. If a transverse section of an anther is examined it will be seen that the wall of the anther consists of an epidermis and a layer of fibrous cells beneath it. At the place where the walls of the pollen sacs join with the septum that separates them, the fibrous layer is not formed.

At this point and all along the length of the anther lobe, all the cells are rounded and thin walled, with intercellular spaces. This arrangement is intended to facilitate the dehiscence of the anther when ripe along this line.

Pollen grains.—When young the anther lobes are rigid and full and their outer surface are unbroken. The cells of the epidermis bulge slightly outwards and they are filled with protoplasm. And it is these young epidermal cells that maintain the turgidity. Until

the **pollen grains** are fully developed the epidermal cells are turgid and are in a living condition, exerting pressure on the fibrous cells. When the pollen grains are mature the epidermis loses water, and the fibrous cells expand and bring about dehiscence. The presence of the fibrous layer and the absence of these cells along the line in front of the septum are conducive to dehiscence. As soon as pollen is shed, the stamens fall away, as they are of no further use.

Just like the flower, the pollen grains also vary very considerably in size, shape, colour and in the marking on the outside. All these difference are only external. The internal structure is more or less uniform in character, whatever the external difference may be. A pollen grain is essentially a bit of protoplasm differentiated into two cells, one being larger than the other. It has two coats, **intine** and the **exine.** Generally the former is uniform thin and smooth, whereas the latter is cuticularised and sculptured in various ways. Of the two cells, the larger one is called the **vegetative cell** and it is this cell that gives rise to the pollen tube. The smaller cell consists of cytoplasm and a nucleus and this cell takes a direct part in the reproductive process. It is called **antheridial mother cell.**

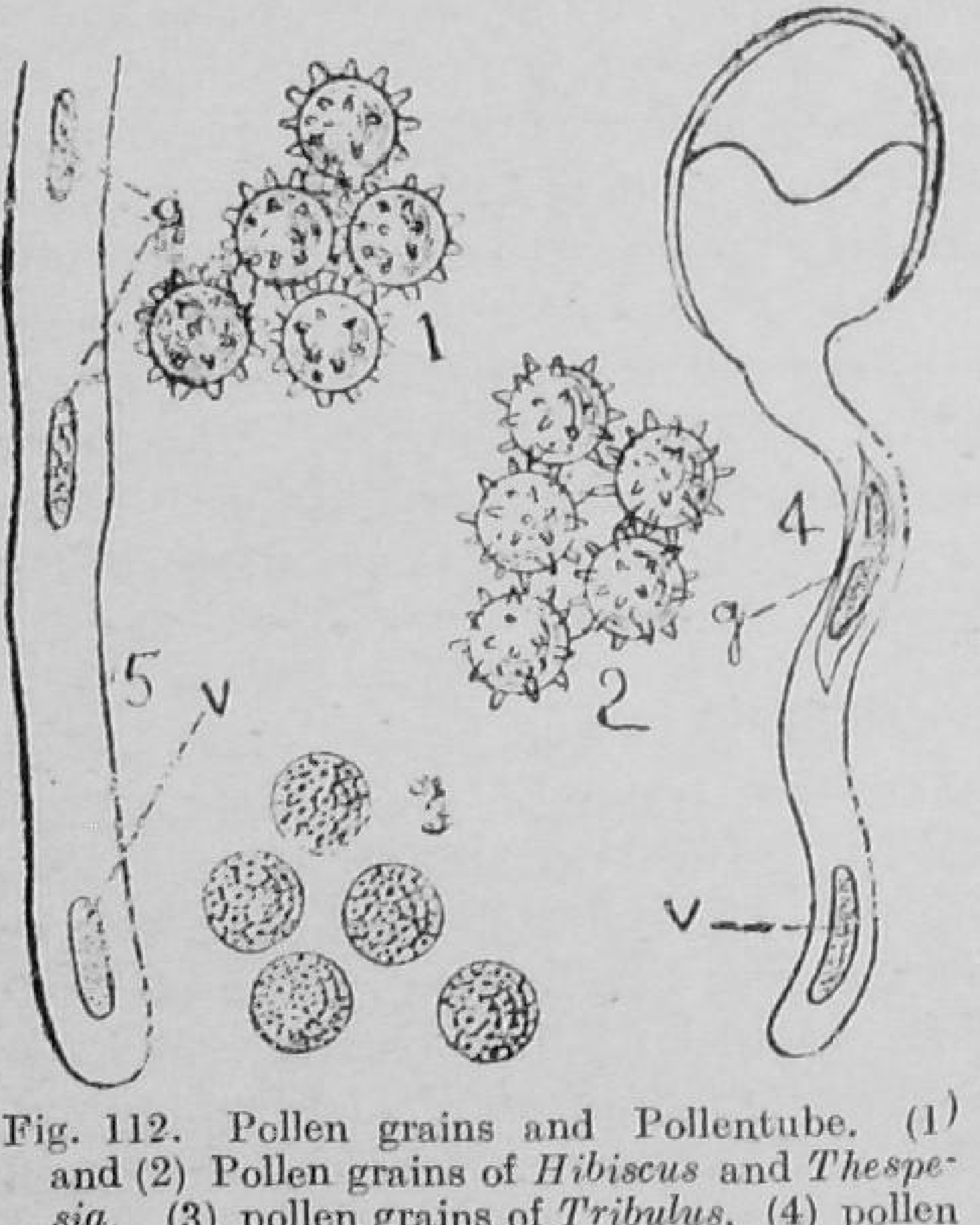


Fig. 112. Pollen grains and Pollentube. (1) and (2) Pollen grains of *Hibiscus* and *Thespesia.* (3) pollen grains of *Tribulus.* (4) pollen Grain germinating. (5) the end of the pollen tube. V. Vegetative cell. G. Generative nuclei.

When the pollen grain germinates on the stigma, it forms a pollen tube which penetrates the style and finally reaches the ovule. At the end of the pollen tube lies the nucleus of the vegetative cell and just above it are seen two nuclei, called the **generative nuclei (gametes).** These two are evidently derived from the nucleus of the antheridial mother-cell (Fig. 112).

Ovule.

The ovule which is within the ovary is usually attached to the placenta by means of a short stalk called the funicle. In form,

ovules are generally oval. An ovule consists of a mass of cells called the **nucellus**, invested almost completely by one or two integuments, except for a small passage termed the **micropyle.** The base of the ovule from which the integuments arise is called the **chalaza**. Variations occur in the ovules as regards their postion on the placenta. In some plants the ovules are erect or **orthotropous** as in *Polygonum*. In this case the ovule is in direct continuation of the funcile. The chalaza and the micropyle are far apart and opposite to one another. (See Fig. 113). The body of

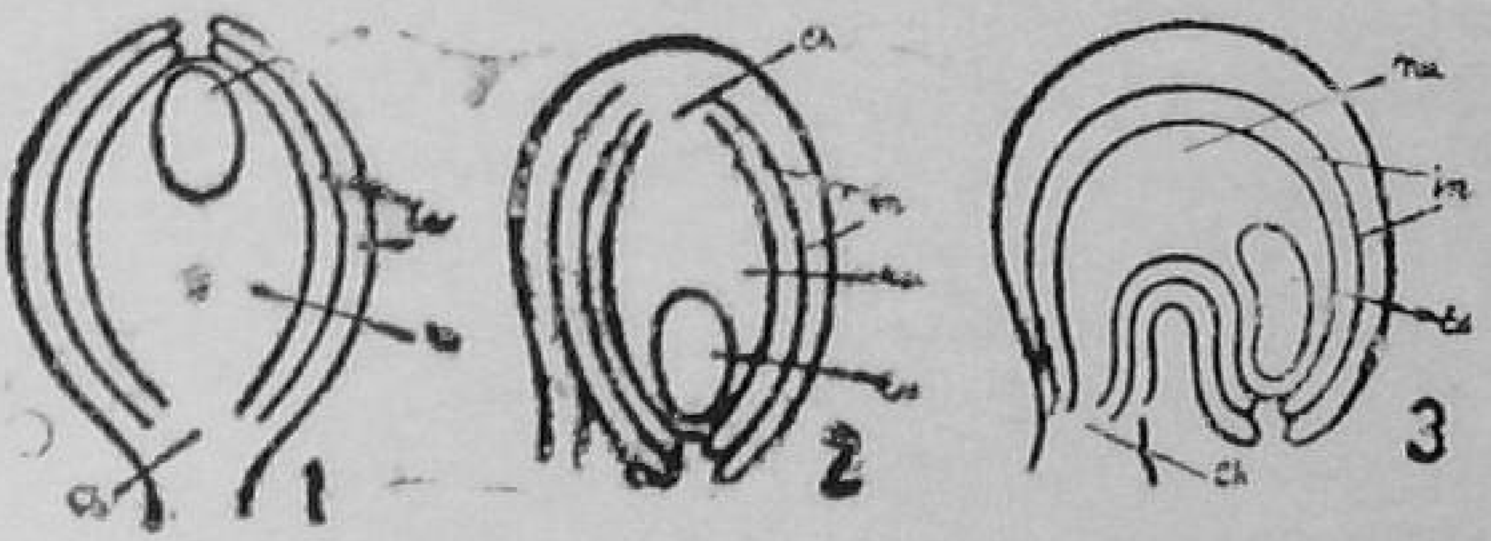


Fig. 11?. Different forms of ovuls. (1) orthotropous. (2) anatropous. (3) Campylotropous. Ch. Chalaza. In. Integument. Nu. Nucellus. E. Embryo-sac.

the ovule may become bent on itself, as in mustard and radish, and then it is said to be **campylotropous.** In this form of the ovule the micropyle and the chalaza lie near the funicle. But the

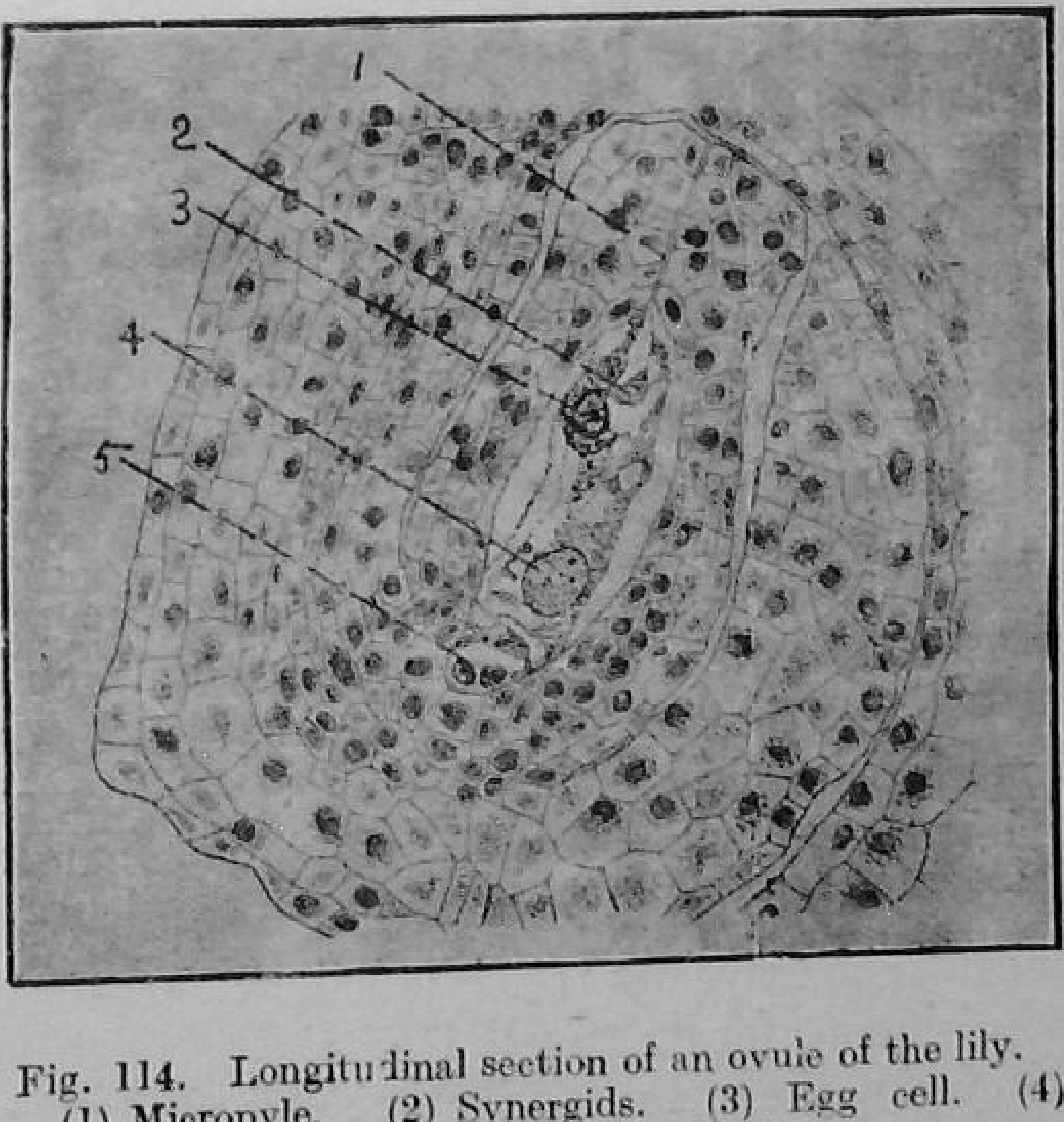


Fig. 114. Longitudinal section of an ovule of the lily. (1) Micropyle. (2) Synergids. (3) Egg cell. (4) Secondary nucleus. (5) Antipodal cells.

commonest form of the ovule is the **anatropous** condition i.e., ovule inverted. In this the micropyle would be opposite to the chalaza but close to the hilum, the funicle being adherent to the integument on one side.

Embryo-sac.—In the early stages of development the ovule arises from the placenta as a mass of cells, and later this forms the **nucellus.** After some time this nucellus becomes covered by the growth of one or two **integuments** from the base of the ovule. Sooner or later, within the nucellus, one cell begins to grow and it becomes larger than all the others This cell is the embryo-sac. Its nucleus, called the **primary nucleus,** divides into two at first and each of these two move towards the ends of the embryo-sac (see Fig. 115). By further division each of these divide into four nuclei. Of these four, three remain at the extreme ends, and one nucleus from each of these groups travels towards the centre of the embryo-sac and both these fuse into a single nucleus. This is termed the **secondary nucleus** and the two before fusion are termed **polar nuclei** (See Fig. 114). The remaining nuclei at the farther ends of the embryo-sac get surrounded by the protoplasm and form naked cells.

When the flower is open, the ovules would be in a fit condition for fertilisation. Within the nucellus lies the embryo-sac with the seven naked cells arranged as described. The three cells at the micropylar end constitute the "**egg-apparatus**" and the larger inner cell of this group is the ovum or **egg-cell.** The other two cells just above and close to it are called the **synergids.** The remaining group of three cells at the chalazal end of the sac are called **antipodal** cells.

Fertilisation.—The pollen grain begins to show its activity as soon as it is deposited on the stigma. The structure of the stigma and its condition at the time of the reception of the pollen grains are adapted to facilitate the germination of the pollen grains. On germination the pollen grain forms a tube (Fig. 112). At first the contents of the vegetative cell passes into the pollen tube, and then the nucleus and the cytoplasm of the antheridial mother cell get into it. The nucleus of the latter divides into two nuclei or **male gametes.** So the nucleus of the vegetative cell will be near the end of the pollen tube and the two male gametes behind this.

The pollen tube traverses the style and reaches the ovule, getting the nourishment for its growth from the tissue through which it passes. Entering the micropyle it reaches the top of the nucellus where the egg apparatus lies. Then the two male gametes, already

formed in the pollen tube, pass into the embryo sac. One of them fuses with the egg cell or ovum, the synergids probably helping in directing the gamete to it. The other gamete fuses with the secondary nucleus lying in the embryo-sac between the antipodal cells and the egg-apparatus. The ovum after its fusion with the male gamete is capable of further division and development into the embryo. The fusion of the second gamete with the secondary nucleus generally takes place long after the fusion of the polar nuclei. In some cases, as in lily, the fusion of the polar nuclei and that of the male gamete may take place simultaneously. The secondary nucleus after this commingling with the male gamete, divides and gives rise to the **endosperm.** In many plants after fertilisation the greater portion of the nucellus tissue disappears, and between the seed coats and the embryo nothing of it remains. But in the case of a few plants, as in pepper and water lily, the nucellus tissue persists and does not get absorbed. This nucellus tissue which persists in the seed is the **perisperm.**

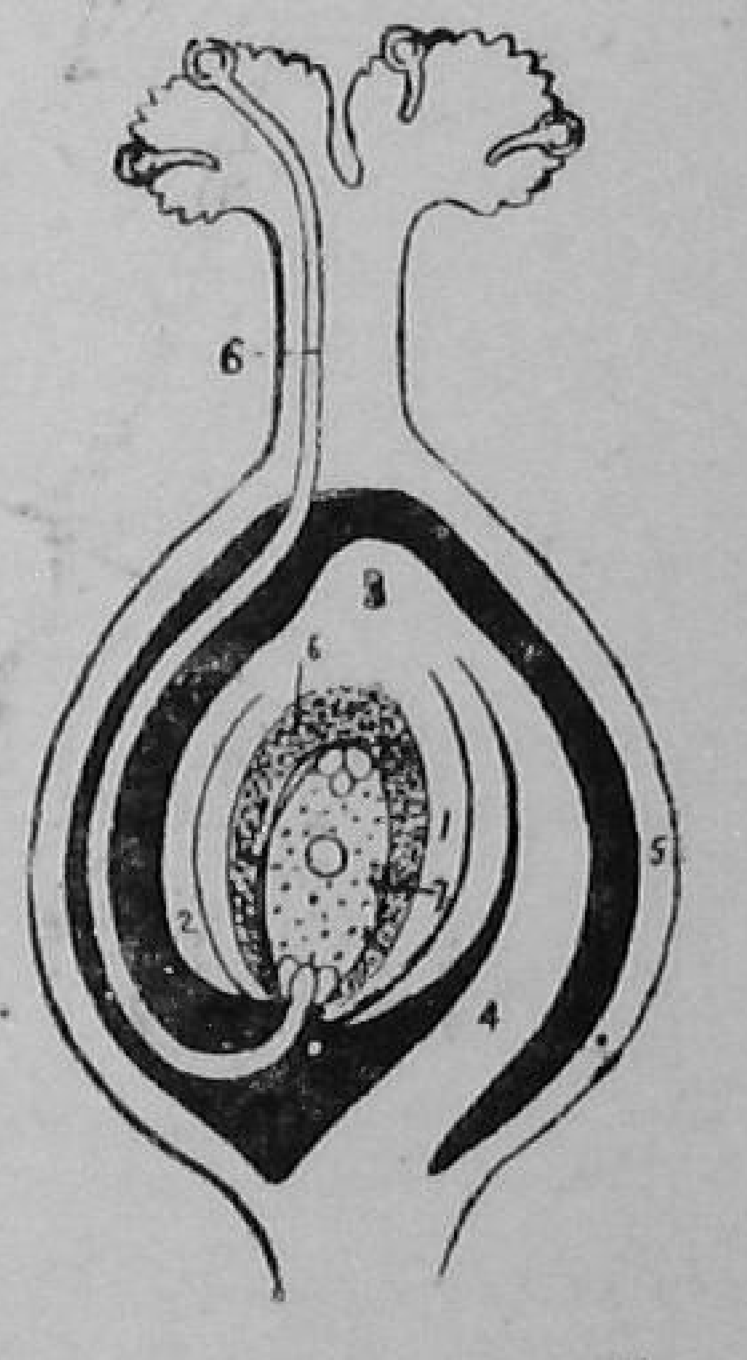


Fig. 115. Diagram to illustrate pollination and fertilisation, (1) and (2) integuments, (3) chalaza, (4) funicle, (5) pericarp, (6) pollen tube, (7) embryo-sac.

The tip of the pollen tube, as a rule, enters the micropyle of the ovule and reaches the nucellus in the vast majority of plants. This entrance of the tube through the micropyle is termed **porogamy.** In some plants, as in Casuarina, the pollen tube enters the ovule at the chalaza and reaches one of the many embryo sacs in the nucellus. This mode of the entrance of the pollen tube into the ovule is called **chalazogamy.** (Fig. 115). Chalazogamy is now known to occur in many plants belonging to the families, Ulmaceae, Urticaceae and Euphorbiaceae.

The time that elapses between pollination and fertilisation is generally very short, although this interval may extend to one year in the case of some Gymnospermous plants. Thus it is clear that in Angiosperms a seed is formed only after this **double fertilisation.** Further details as to the significance of this fusion and its influence on the embryo are dealt with elsewhere.

Pollination.

We now know that for the formation of seeds pollen is absolutely necessary, because the male gametes fertilising the ovum and the secondary nucleus are formed in the pollen grains. In consequence of the higher plants being rooted to a place and the pollen grains being incapable of movement, some extraneous aid is necessary for the conveyance of pollen. Even in the case of hermaphrodite flowers pollen grains have to be carried to the stigma. The agencies that are helpful for pollination are **wind, insects** and **water.** The conveyance of pollen grains of a flower to its stigma or to the stigmas of flowers on the same plant is **self-pollination.** If the pollen is carried to the stigmas of flowers on a different individual, it is **cross-pollination.**

Fig. 116. Cleistogamous flowers of *Commelina benghalensis.*

The vast majority of plants have hermaphrodite flowers, and so it may be assumed that no special arrangement would be necessary for pollination. But extended observation shows that adaptations of very complex nature exist and that all the manifold modifications of the flowers of Angiosperms are meant to facilitate pollination.

Self-pollination.—Although cross pollination is more advantageous to plants than self-pollination, there are several plants in which self-pollination is very common. For instance, the chenopodiums, cotton, paddy, etc., have flowers that are self-pollinated. Generally self-pollination occurs in plants having inconspicuous flowers with sticky pollen.

Self-pollination or autogamy usually occurs in the flowers of many plants. Many of the weeds, especially annuals, are holding their own in most places and become dominant because they are usually self-pollinated and do not need any extraneous aid for pollination. In plants, in which self pollination is the rule, cross pollination may occassionally occur, thus enabling them to keep up their strength and fertility. There are some plants which

unite the two methods by producing ordinary showy flowers and also inconspicuous closed or **cleistogamous** flowers. For example *Commelina benghalensis* (Fig. 114). produces pretty blue flowers that are very conspicuous and also white inconspicuous flowers which are under ground. The former are cross pollinated and the latter are self-pollinated. In Viola also cleistogamous flowers are known to occur.

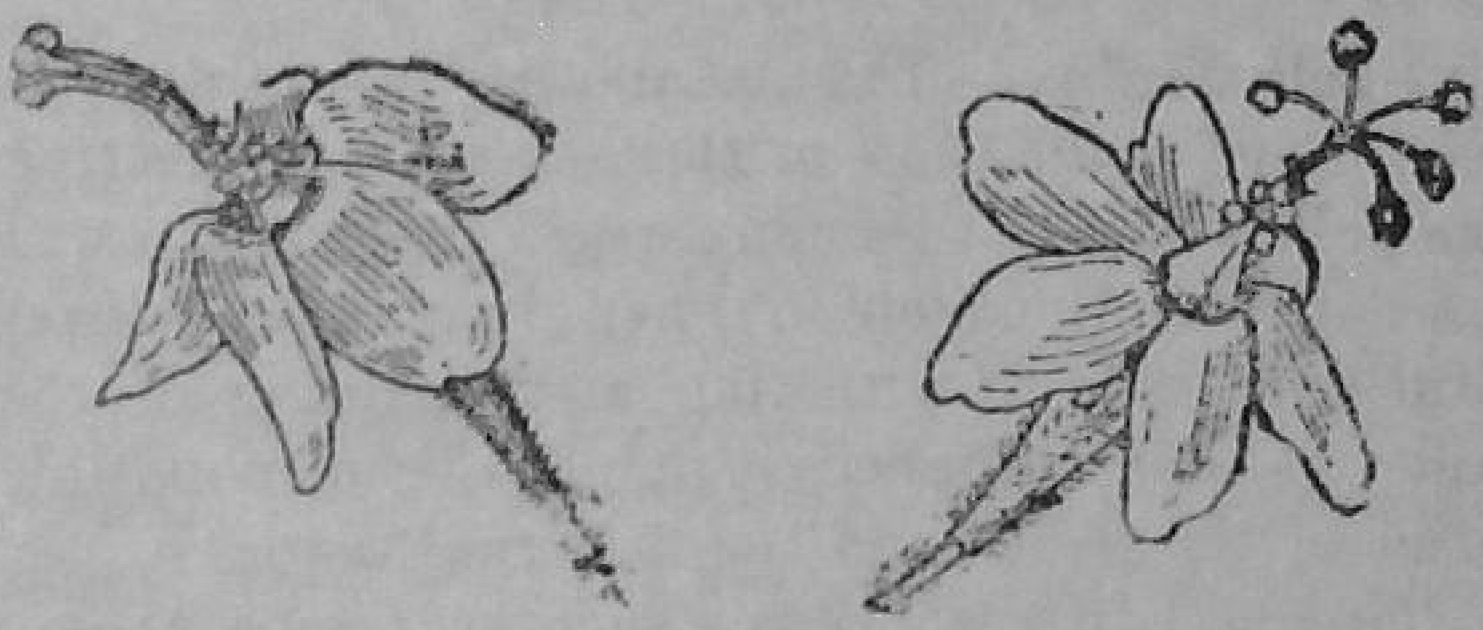


Fig. 115. Flowers of *Hibiscus micranthus*.

There are flowers having the stigmas and the anthers far enough apart to make self pollination impossible when they first open. Later, however the anther and the stigma come into contact. As an example for this we may mention the flowers of *Hibiscus micranthus* (Fig. 115). In the flower, just when it opens, the stigmas project far above the anthers and so the pollen cannot reach the stigma. If the stigma do not receive foreign pollen, they bend down, so as to come in contact with the anthers in the same flower, and thus self-pollination is effected. Other examples of flowers, having this kind of adapation in their floral mechanism to secure self-pollination if cross-polleination fails, are those of several species of Malvaceæ and Compositæ, *Mirabilis Jalapa* and *Evclvulus alsinoides*.

Cross-Pollination

(i) **Dicliny.**—In spite of the fact that the vast majority of plants possess hermaphrodite flowers, cross fertilisation appears to be more common, and the adaptations to favour this method in preference to self-pollination are indeed many. Even in a flower in which self pollen may not be entirely sterile, self-pollination is made difficult if not altogether impossible. When plants are **monœcious** or **diœcious** self-pollination is out of the question. Such flowers are termed **diclinous.**

(ii) **Dichogamy.**—In many a plant self-pollination is rendered impossible by the essential organs attaining maturity at different times. This condition is usually known as **dichogamy.**

The stamens ripen very much earlier than the stigma of the same flower so that the pollen can be useful only for cross-pollination. Such flowers as these are **protandrous.** Flowers of Compositae Malvaceæ, Geraniaceæ and Umbelliferæ are protandrous. In some flowers, as in *Pennisetum typhoides*, stigmas mature earlier than the stamens and these are **protogynous.** Such flowers are common in species of *Euphorbia* also. Protandry, however, seems to be more common than protogyny.

(iii) **Self-sterility.**—This is another adaptation for cross-pollination. Self-pollination in these cases is ineffective because either the pollen does not germinate or if it germinates, the pollen tube does not reach the ovule in time. In orchids, self-pollination is harmful and leads to withering and shedding of the flower. Self-sterility in many instances is due to the incompatible genetic constitution of the pollen and the maternal tissues in stigma and style or the egg. In some plants such as *Linum* there are two or more forms of styles and stamens viz., the flower may bear long stamens and short style or short stamens and long style. The compatibility is between long stamens and long style or short stamen and short style. This condition is termed **heterostyly.**

(iv) **Herkogamy.**—In some hermaphrodite flowers, self-pollination is prevented by the presence of barriers which prevent the pollen grains from reaching the stigma. The anthers and stigma may be separated by some distance or one of them may be hooded by the petals. These are contrivances for cross-pollination and are found in Orchids.

Agents for cross-pollination. (i) **Anemophily.**—A large number of spermatophytes depend for their pollination on wind. For instance, in all grasses and many deciduous trees the pollen is wafted on the stigma by the wind. Such plants are called **anemophilous** plants. Where use is made of wind for the conveyance of pollen grains to the stigma, we notice certain features in the flowers that should be considered as special adaptations to favour pollination. In the first place wind is proverbially unsteady and as such the pollen grains that may be blown on to the stigma cannot be very many. Consequently, to minimize the chances of failure and to effect pollination with certainty, a large amount of pollen is usually formed in the flowers of anemophilous plants. The pollen grains also are light, dry and smooth. The stigmas also in such flowers are plumose and very much branched so as to offer the largest amount of surface for the reception of pollen (Fig. 116). The anthers also are so attached to their filaments that they may be

shaken and made to shed their pollen even when slightly disturbed by the wind. The anthers are, in other words, versatile.

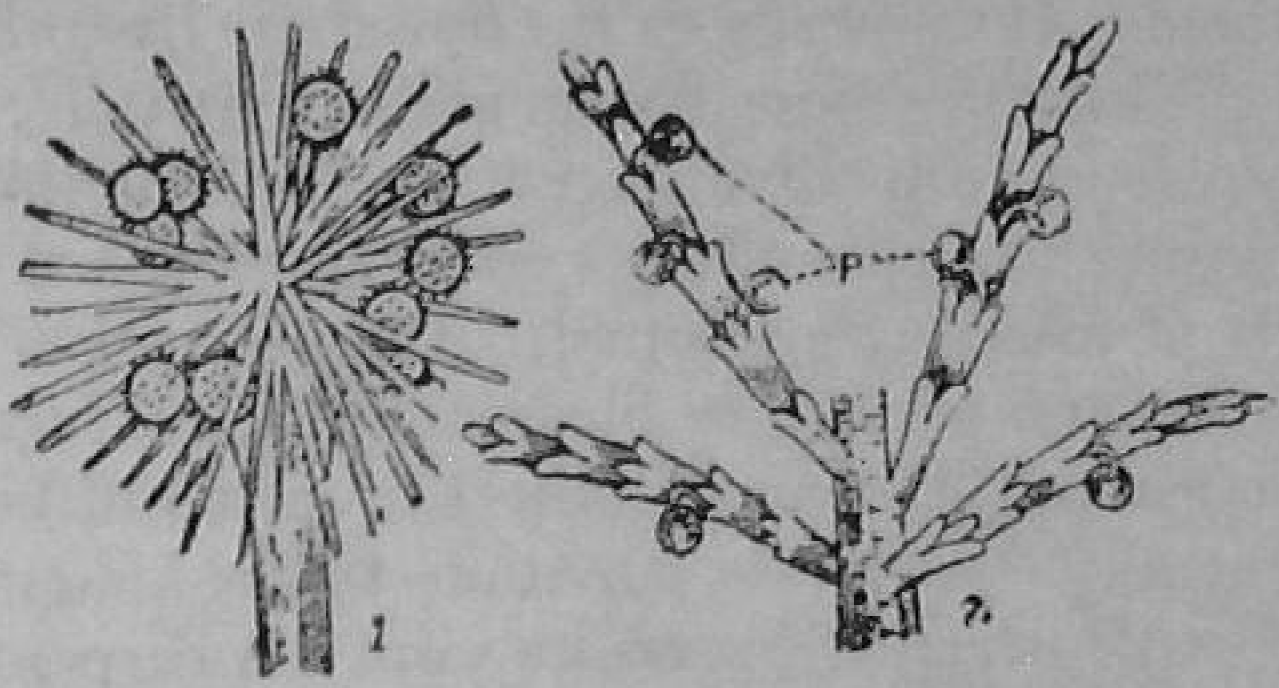


Fig. 116. Stigmas of (1) *Hibiscus* and (2) of a grass plant.

The inflorescence, as may be seen in all grasses and cereal plants, is usually lifted far above the level of the foliage. In deciduous trees flowers occur long before the appearance of the leaves. This is advantageous, because there is nothing to impede the passage of the pollen. The tree *Odina Wodier*, is bereft of leaves when in flower. It must also be noted that anemophilous plants are devoid of scent and colour. The occasional occurrence of a reddish colour in certain anemophilous plants is not intended for pollination, but is said to help the plant in absorbing heat rays.

In this connection it must be noted that flowers producing pollen in abundance are more primitive than those in which the stamens are few and hence producing a small amount of pollen. The earlier seed-plants were evidently related to the cone-bearing plants represented at the present time by pines and cycads. The anemophilous plants are, therefore, more primitive than those pollinated by insects. The excessive production of pollen when wind is the pollinating agent is very wasteful though necessary. In the course of evolution, to prevent this waste, flowers have adopted specialisation. The gamopetalous flowers and orchids are evidently plants in which the flowers have been specialised so as to secure pollination through the agency of insects.

Entomophily.—Among phanerogams in a great majority of plants pollination is effected by insects, and such plants are known as **Entomophilous** plants. The insects that usually visit flowers are bees, flies, butterflies and moths. All these insects have sucking apparatus, which in the case of flies and bees are short and in butterflies and moths they are long and coiled like a spring. All these insects visit the flowers, because they find in them honey and rich pollen. Both these substances are eagerly sought by bees as food, but butterflies and moths drink only honey.

As a rule insects effect cross-pollination and for the success of this process, flowers should be regularly and systematically visited by them. If the visits to the flower are irregular and only casual, or if the insects choose flowers indiscriminately, pollination cannot take place to any advantage. As the secretion of honey and the exposure of pollen always occur when the flowers open, regular visits of insects are ensured. The presence of colour and scent in the flowers, when they blossom forth, are further attractions for the insects. By careful observation it will be seen that an insect generally confines its attentions to the kind of flower for a long time, with which it begins its visit. A carpenter bee was once seen while sucking honey from the flowers of *Bauhinia tomentosa* and it continued to seek the same flower for over an half-hour avoiding all the flowers that were near. At another time its visits were confined to *Dolichos Lablab* flowers. Butterflies on one occasion, began their visits with *Justicia and Tephrosia* and continued to do so for over an hour.

Flowers pollinated by insects produce only a small quantity of pollen and so stamens are usually fewer in number. The pollen grains have rough surfaces and are studded with spines or other devices and are usually sticky. In short, the various adaptations, particularly of flowers that are specialised, are so perfect that pollination is a certainty.

Flowers that are actinomorphic and shallow and those with short tubes are usually visited by a large number of insects. For example, in the *Tribulus terrestris* flower honey is secreted by glands at the base of the stamens and between the petals. The stamens are erect and are about the same height as the stigma when the flower is open. So any insect can get at the honey, and at the same time its body will be dusted with pollen and that pollen dusted part of the body will come in contact with the stigma of another *Tribulus* flower, when it goes to it. The flowers of *Tridax* and *Taraxacum* are usually visited by a number of insects. At least a dozen kinds of insects may be seen to visit the former and in the case of the latter, one observer records that about one hundred kinds of insects are known to visit it.

Flowers with long tubular corollas such as those of *Ipomoea, Jasminum* and *Vinca* and papilionaceous flowers are not visited by many insects, because the honey is hidden and only long tongued insects can get at it. All these flowers are highly specialised for cross-pollination by particular insects. A careful observation nil reveal a definite adjustment existing between the floral mechamisl of these flowers and the kind of insect visiting them. In

SALVIA - Details to show cross-pollination by insect

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these flowers the nectary will be so situated and the arrangement of the parts would be such that an insect cannot get at the honey, without some part of its body brushing against the pollen in the anthers. For successful cross-pollination by the visits of the insect, it is absolutely necessary that the part of the body of the insect that gets dusted with the pollen should also come into contact with the stigma.

Colour of petals, though intended to show off well by contrast, is probably not capable of attracting insect so well, as the scents of flowers and the smell of honey. For example, the flowers of *Mirabilis jalapa* are visited by hawk moth during evenings and even after dusk. There are several varieties of this plant and the colour of the flower are white, cream, yellow, red and magenta. In all the varieties the flowers open only towards the evening and they emit a strong scent. In the dusk flowers that are white, light yellow or cream coloured alone can be seen and the red and magenta flowers cannot be seen, judging from our own experience. Yet the moths visit the flowers of all colours with equal ease. As already stated, some flowers are highly specialised and can be pollinated only by the visits of particular kinds of insects. As examples, we may consider the flowers of *Crotalaria verrucosa, Phaseolus trilobus* and *Habenaria platyphylla.*

The flowers of Papilionaceæ are specially adapted for cross-pollination in several species (Figs. 96 & 117). In *Crotalaria verrucosa* there is a disk round the ovary at the base secreting honey, and this honey flows into the staminal tube. As the staminal tube and the ovary are within the keel petals, insects cannot easily get at the honey. Wing petals are spread out at the sides just above the keel petals so as to form a platform for the insects to sit on. The standard is generally very conspicuous and it stands erect above the wing petals. Insects settle down on the wings and begin to search for the honey at the base of the standard. While the insect is moving about, the wing petals go down a little and press the keel petals. This causes the pollen dust to be ejected from the tip of the keel petals and some pollen dust must necessarily fall on the body of the insect. This ejection of the pollen can be very well seen in the flowers of *Crotalaria juncea* when they are visited by bees. At first in one flower the bee gets dusted with pollen and, when it goes to another flower, the stigma touches that part of its body which is covered with pollen.

In the flowers of *Phaseolus trilobus* (Fig. 117) the keel petals are prolonged into a spiral beak, and the end of the spiral is towards

the right side, looked at from the front. The right keel petal possesses a spur which supports the right wing petal and helps it in retaining a horizontal position. This serves as a platform for the insect visiting the flower. The arrangement of the petals, stamens and the stigma is such that an insect can get at the honey only from the right side. To get at the honey it has to pass between the right wing petal and the end of the keel spiral. The insect has to alight on the lower wing petal and when it does so there will be some pressure exerted on the keel petal. When the insect moves on the platform the keel petal must also get depressed

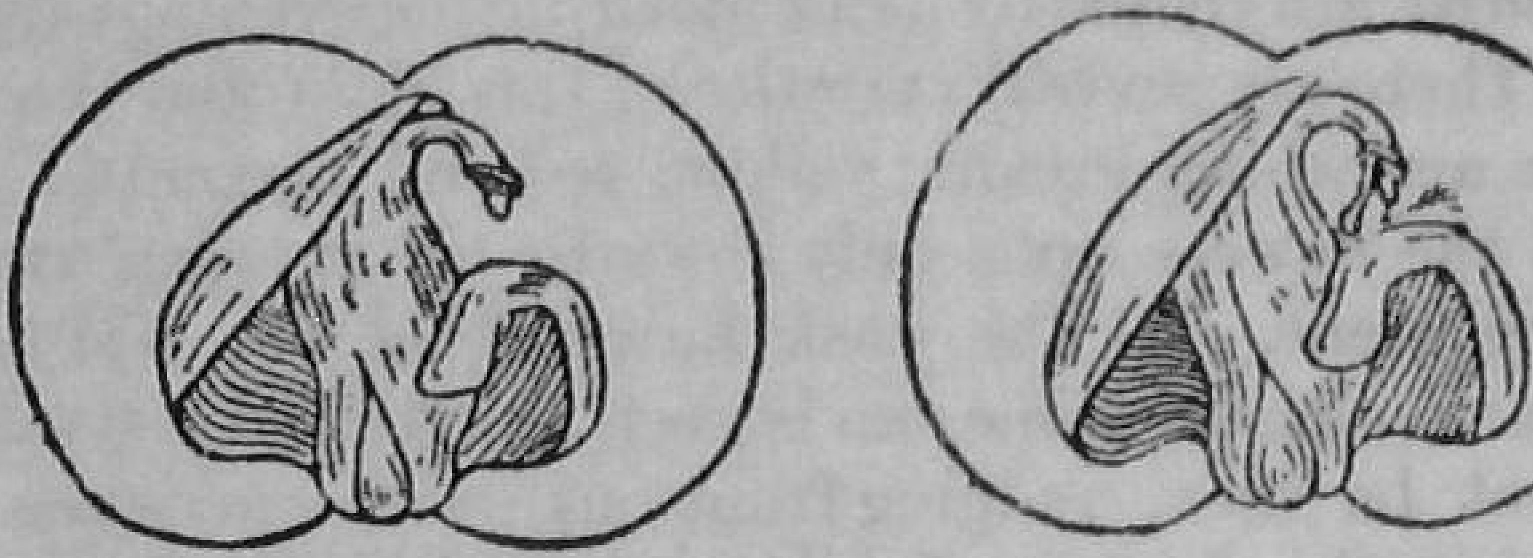


Fig. 117. Front view of the flowers of *Phaseolus trilobus*.

because of its spur supporting the wing petal. This depression causes the stamens and the stigma to pop out at the end of the spiral. If the insect visits a flower at first its back will be dusted with pollen. When it visits another flower, the back of the body comes in contact with the stigma and pollination is effected.

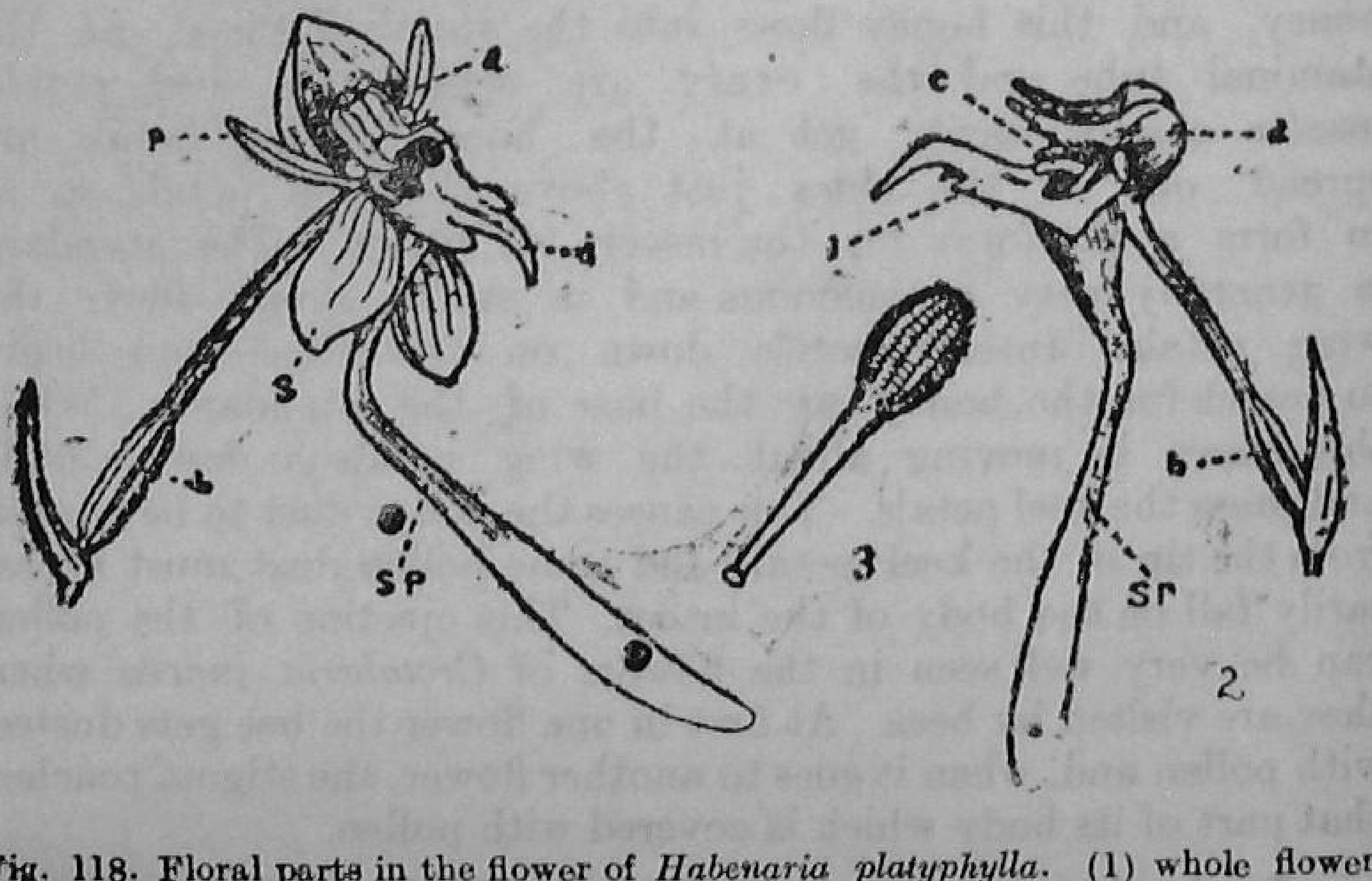


Fig. 118. Floral parts in the flower of *Habenaria platyphylla*. (1) whole flower (2) flower without the calyx and corolla (3) pollinium. s=sepal; p=petal; a=anther; b=ovary; c=stigma; sp=spur; l=labellum.

In the flowers of orchids we have a most perfect mechanism for securing cross-pollination although it is very complicated. The flowers of the orchid *Habenaria platyphpylla* are visited by moths in the dusk both morning and evening (Fig. 118). These flowers are pure white and are in racemes. In the flowers there are three broad sepals, three petals of which two are narrow and the third modified into a lip with a long hollow spur at its back. The two lateral petals and the sepal lying above are together so as to form a hood. There is a narrow passage leading into the interior of the flower, and the anther is situated on a column just above the passage leading into the spur. The pollen grains in this flower are collected together into two masses called the **pollinia.** Each pollinium has a long stalk whose basal portion protrudes a little. When the moth visits the flower and tries to drink the honey in the spur, the pollinia stick on to the head of the insect and when it flies to another flower the pollinia are rubbed against the stigma lying below the anthers and the pollen masses adhere to the stigma, as its surface is sticky.

We have many plants in which the flowers are pollinated by moths. As moths move about only in the dusk, flowers they visit have white corolla-as for example, the flowers of *Ipomoea bona nox* or the moon flower are white and tubular with its limb spread out and regular. Further, these flowers give out a strong scent in the dusk of the evening. The flowers of *Mirabilis* and *Jasminum* are also pollinated by moths. In all these flowers the anthers are generally loose and are well adapted to shed the pollen on to the body of the hovering moth. The hawk moths *Herse convolvuli* and *Cophanodes picus* visit the flowers of many of the large flowered species of *Ipomœa* and *Mirabilis Jalapa*. The former is a very constant visitor, but the latter one comes occasionally and it is extremely active and its motions are very rapid.

Hydrophily.—Submerged water plants depend for their pollination on water. Plants such as *Ottelia alismoides*, *Hydrilla verticillata* and *Vallisneria spiralis* (Fig. 120) have their flowers pollinated on the surface of the water in which they live. Such plants are termed *hydrophilous*. Most of these species of plants have uni-sexual flowers. Both the staminate and the pistillate flowers develop under water, and at the time of flowering the staminate flowers get separated from their stalks and rise to the surface and float on water. Staminate flowers are formed in large numbers. The stalks of the pistillate flowers elongate so that stigmas may be just on the surface of the water. The male flowers

floating about on water, come near the stigmas by the movement of water, and pollination is effected.

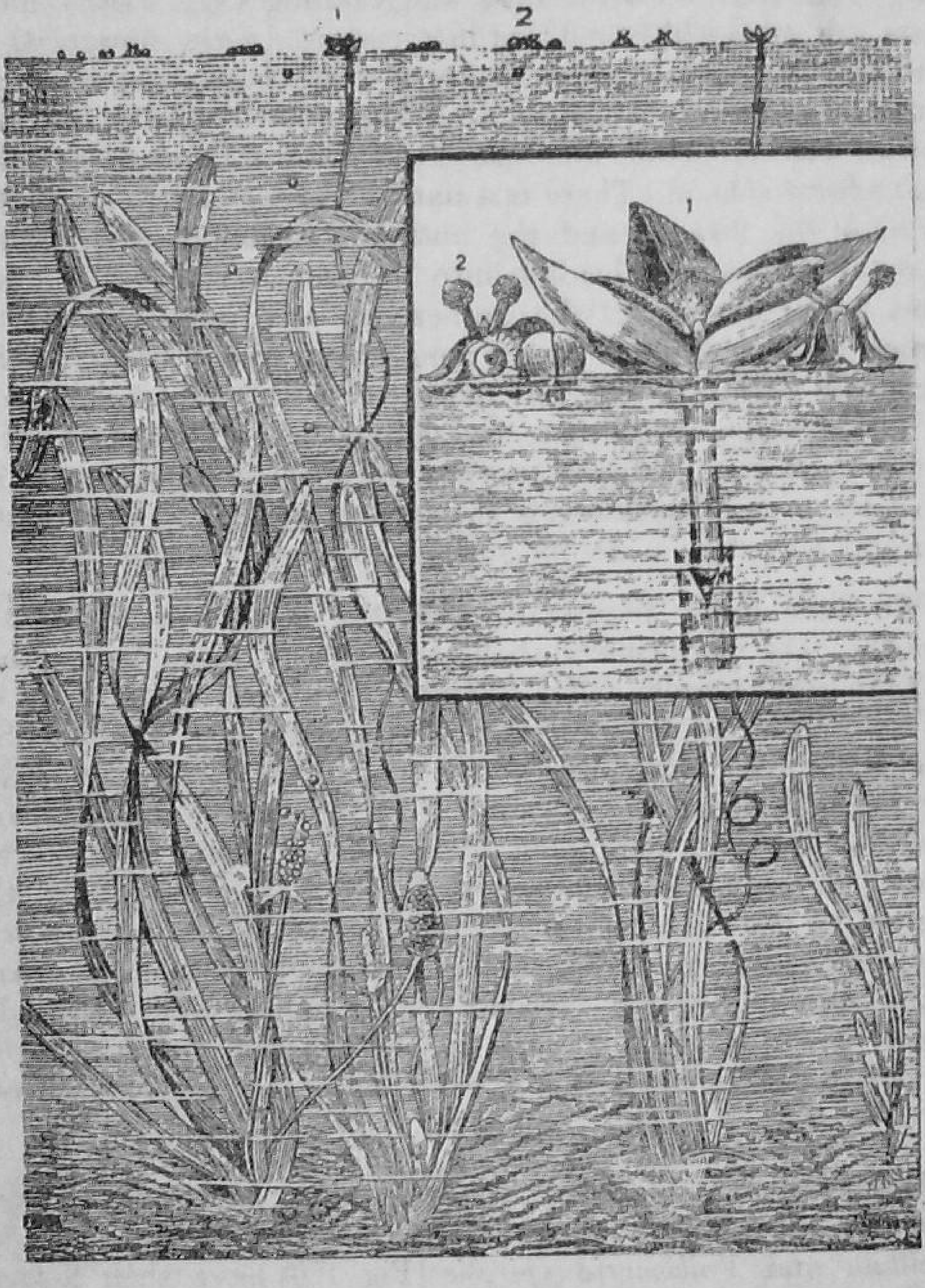


Fig. 120. Hydrophilous flowers of *Vallisneria spiralis*. (Inset) details of male and female flowers.

CHAPTER X

FRUIT AND SEED

Development of fruit.—A fruit is the ripened ovary or the gynæceum. Whem the flower blooms, the accessory parts fall apart and expose he essential organs. After pollination, fertilisation of the ovules takes place. This is an important phenomenon in that it provides the necessary stimulus for the development being responsible for many evolutionary and genetic significances which will be discussed later. After fertilisation, the pistil develops into fruit. Very rarely the pistil develops into fruit without fertilisation as in banana. This type of development is termed **parthenocarpy.** In such cases, the ovules do not develop into seed. In some cases, seeds develop without fertilisation of ovules, and this phenomenon is termed **parthenogenesis.**

In the case of annuals, the flowering and fruit formation lead to the death of the plant. Multiennials like *Agave* also die down soon after flower and fruit formation. There is a general change in the physiology and development of the plant consequent to flowering and fruit formation.

Although the immediate object of fertilisation is the formation of the embryo with its reserve food, it also induces the development of the various parts of the ovule. The influence of fertilisation often extends to the other parts of the gynæceum and the flower. As a rule, changes occur in form, structure and size in the carpels, placenta and seeds but other parts also are occasionally subject to changes. From morphological point of view, the fruit is not a new thing. We find in it only those parts that were in existence in the gynæceum, but considerably altered in size and structure. For instance, before fertilisation the ovary is very small in *Cucurbita* and coconut and after fertilisation it develops into big fruit in both these plants. The changes taking place are only physiological. But if we consider the parts of the ovule we find in it after fertilisation something new, namely embryo and the endosperm.

Within a few days after fertilisation, the calyx, and stamens wither and are shed. The pistil begins to enlarge and develop into fruit. Rarely, the calyx is persistent or accrescent. In the achenes of Compositæ calyx persists as pappus, in brinjal it is accrescent. In some instances the accessory parts persist as devices for the dispersal of the fruit. In *Xanthium strumarium* the persistent involucre of bracts develop into spines; in *Pupalia* the sterile flowers form the hook-like bodies round the fruit. In *Achyranthes* and *Alternanthera* the scaly perianth parts are stiff

and pointed, in *Gyrocarpus Jacquini* and *Ventilago* the sepals remain as wings for dispersal. In some instances the stimulus due to fertilisation may extend even to the thalamus; e.g., the thalamus in *Anacardium occidentale* (Cashew-nut). In fig it is the hollow thalamus that develops into fleshy body. In pears and apples, the thalamus grows vigorously and surrounds the achenes in the centre.

Fruits may be classified as shown in the accompanying table:—

- FRUITS.
  - True.
    - Simple.
      - Mono carpellary. Legume. Lomentum.
      - Poly carpellary.
        - Syncarpous.
          - Dry.
            - Dehiscent. Capsule. loculicidal. septicidal. septifragal. Silique. Pyxidium.
            - Indehiscent. Schizocarps (Partial debiscence.) Achenes. Caryopsis. Cypsela. Samara. Nut.
          - Fleshy and Indehiscent Berry. Hesperidium. Pepo. Drupe. Pyrene.
    - Aggregate. (Polycarpellary)
      - Dry.
        - Dehiscent. Follicles.
        - Indehiscent. Achenes.
      - Fleshy. Aggregate of Berries. Aggregate of Drupes.
    - Multiple. Sorosis. Syconium.
  - False. Pome.

There are instances where the whole inflorescence develops into a single fruit, e.g., pineapple, jack and mulberry.

From what is said above it is obvious that the nature of the fruit depends upon the nature of the gynæceum to a certain extent. If the gynæceum is apocarpus, the fruit also is apocarpous. The gynæceums in *Ranunculus*, *Michelia* and *Polyalthia* are apocarpous and so are their fruits. Each of these free carpels in the fruit is considered to be a fruit. The pericarp is dry in *Michelia* and *Ranunculus*, bursting open in the former and not opening in the latter. In *Polyalthia* the pericarp is fleshy and so the carpels do not dehisce. A syncarpous ovary results in a syncarpous fruit and its carpels are consolidated into a single body. As examples, we may mention the fruits of *Argemone*, *Sida* and *Abutilon*.

A fruit formed from a single flower, and consisting of a single carpel or many carpels, all united and consolidated into one, is termed a **simple fruit.** If the fruit is made up of more than one carpel and all free, originating from a single flower, it is called an **aggregate** fruit.

When the fruit is formed from an inflorescence that is from the carpels of more than one flower it is called a **multiple** or **composite** fruit.

Simple Fruit

Generally fruits enclose one or more seeds, and in the simplest case it consists of seeds and pericarp only. In many fruits the pericarp remains fleshy and succulent while it becomes dry in others. So fruits are also grouped into dry and fleshy fruits. It must however be remembered that this separation is purely artificial because in nature there is no sharp distinction between dry and fleshy fruits.

A. Dry fruits.—Dry fruits may consist of a single carpel or many carpels, free or united. If there are many seeds in the fruit it bursts open, and it does not do so if there is only one seed. In syncarpous fruit the carpels either open at the back and liberate the seeds, or break into as many segments as there are carpels. Fruits having many seeds in them must of necessity dehisce, if not all the seeds will germinate in close proximity to one another and the

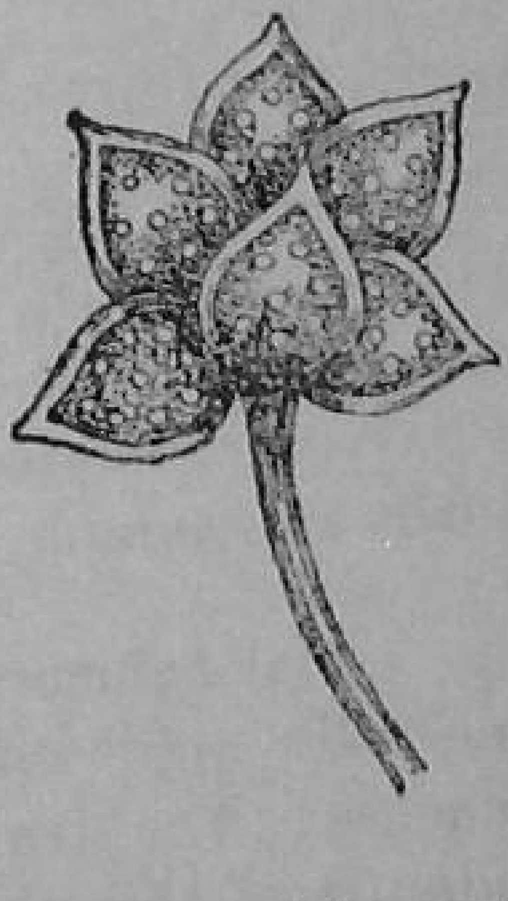


Fig. 121. Achenes of *Ranunculus*.

seedlings suffer on account of keen competition. Single seeded fruits do not dehisce, and the seeds are set free ultimately by the decay of the pericarps. So dry fruits are either indehiscent or dehiscent.

(i) **Achenes.**—The fruits of *Ranunculus* (Fig. 121) *Naravalia* and *Clematis* are apocarpous and each of the free carpels contains a single seed and the fruit is indehiscent. Such fruits as these are termed **achenes.**

(ii) **Cypsela.**—The inferior fruits of sunflower and other plants of the family Compositæ are one seeded and indehiscent. So they are also one type of achenes called cypsela.

(iii) **Caryopsis.**—In achenes the seed coats merely lie in close contact with the pericarp and there is no fusion. There are also single fruits in which the pericarp fuses with the seed coat. This is so in the fruits of grasses, and such fruits are termed **Caryopsis** or **grain.**

(iv) **Samara.**—Sometimes an achene-like indehiscent fruit becomes winged and, then it is called a **samara.** The fruits of *Ailanthus excelsa*, *Hardwickia binata and Pterolobium indicum* are samaras.

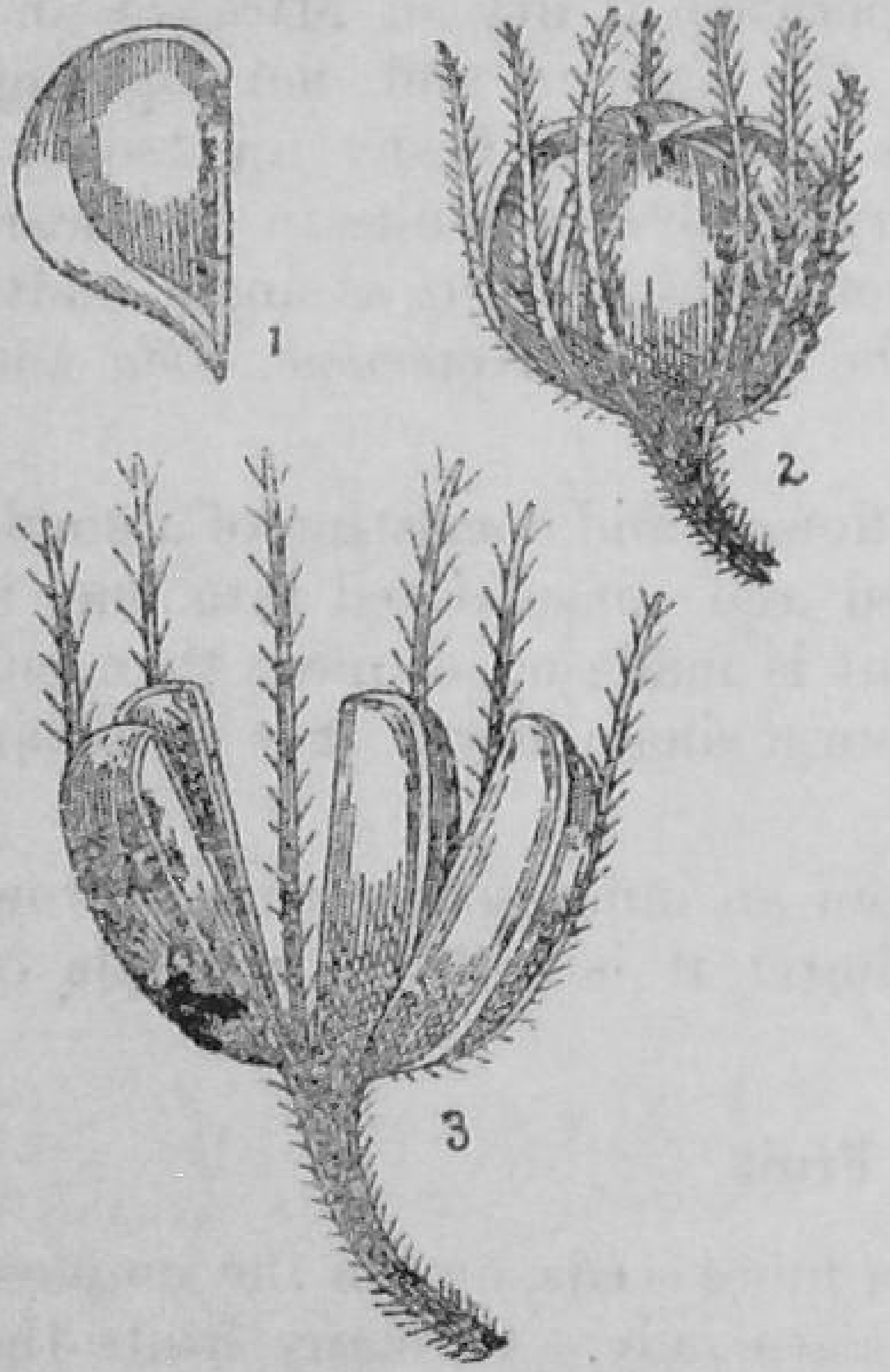


Fig. 122. Schizocarp of *Pavonia Zeylanica.* (1) Coccus or a segment; (2) fruit; (3) fruit with cocci separate.

(v) **Nuts.**—In some fruits the pericarp becomes hard and woody forming a shell, as in Oak and Beech. These fruits are called **nuts.** Coconut is a near approach to a nut, but the shell is only the inner portion of the pericarp. The true fruit in cashew nut is an example of nut.

(vi) **Schizocarps.**—There are many seeded dry fruits which generally split into a number of one seeded parts resembling achenes. The fruits of *Pavonia* (Fig. 122) *Leucas*, castor and Sida are of this nature. The fruit breaks into as many segments as there are carpels. Such fruits as these are termed **schizocarps** and the individual segment cocci. As stated above the coccus is

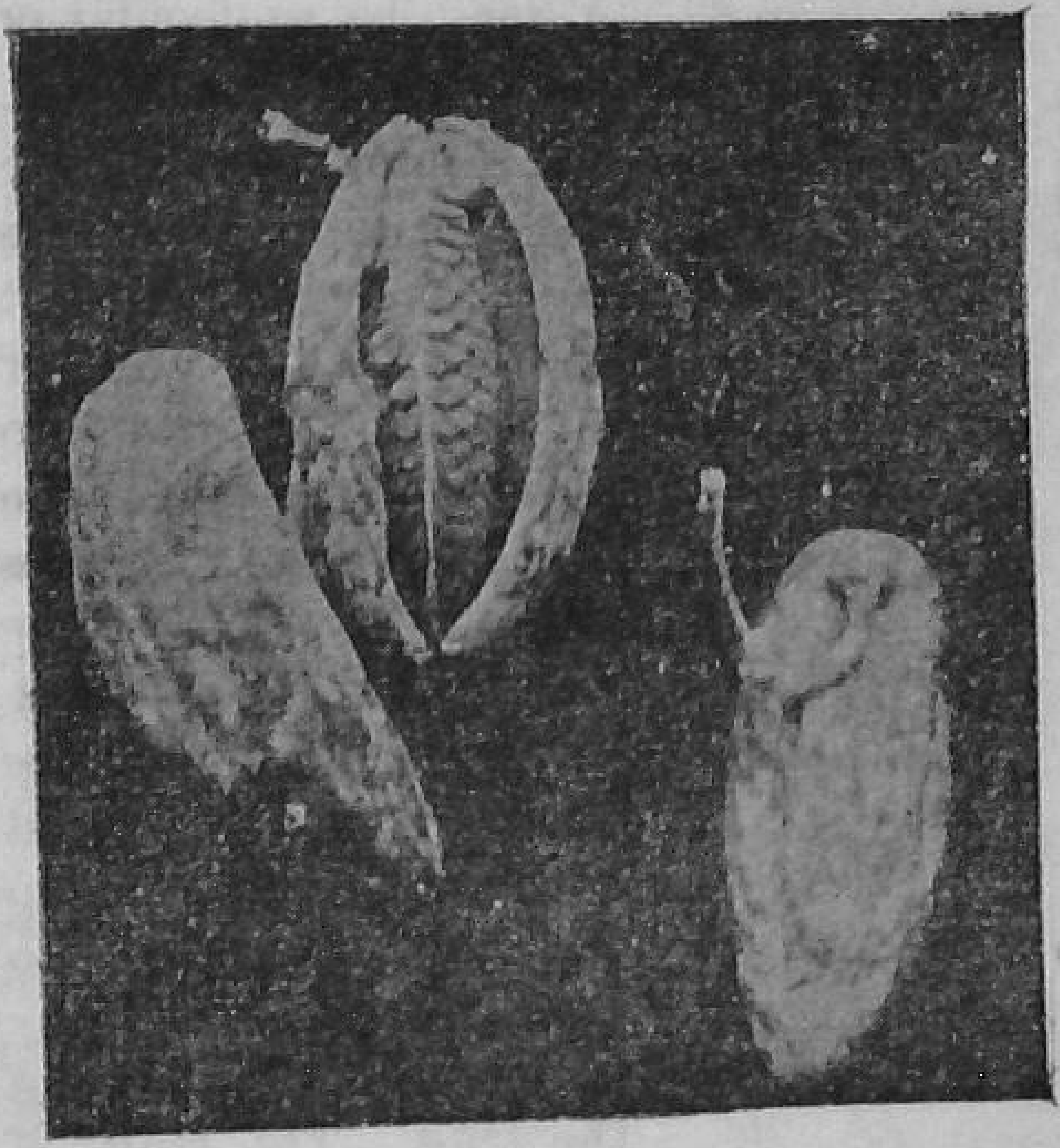


Fig. 123. Follicle of *Calotropis gigantea.*

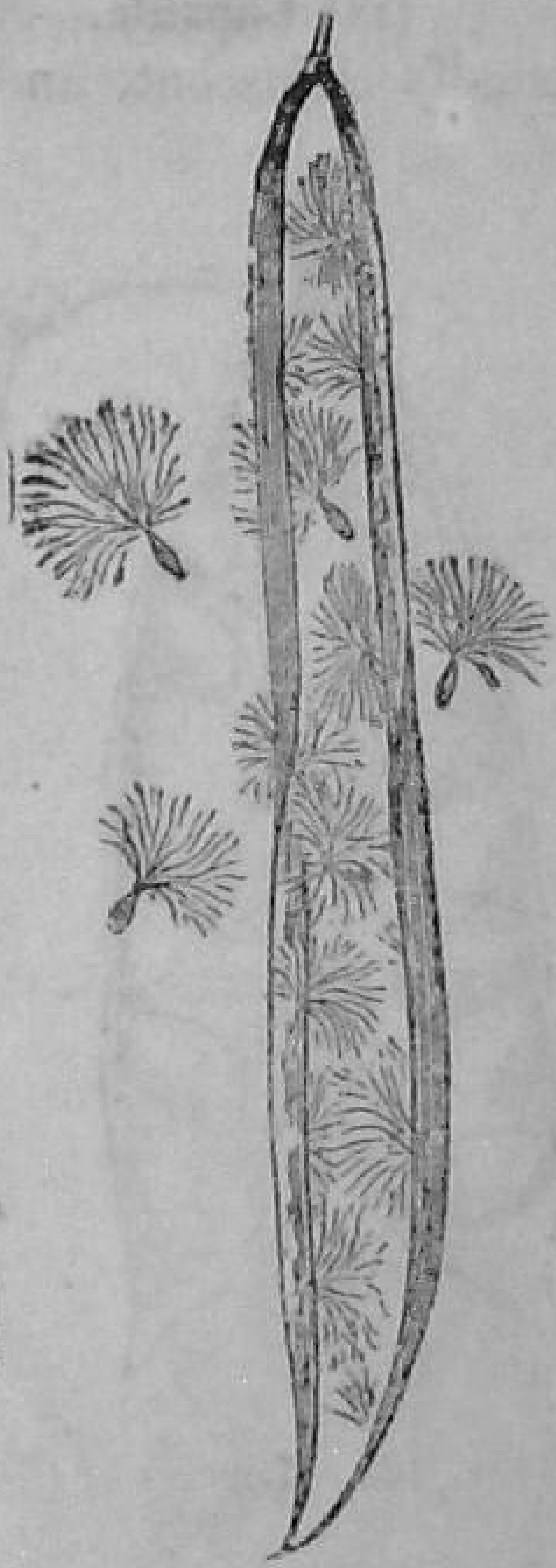


Fig. 124. Follicle of *Wrightia tinctoria.*

indehiscent in *Leucas, Pavonia* and *Sida*, but sometimes they also dehisce as in *Ricinus.*

(vii) **Follicles.**—Fruits of *Calotropis gigantea* (Fig. 123) *Lochnera rosea Wrightia tinctoria* (Fig. 124) and *Sterculia fœtida* are apocarpous fruits and their individual carpels dehisce to shed their seeds. These fruits open by only one suture, the ventral suture which bears the seeds and are called **follicles.**

(viii) **Legume.**—The fruits developing from a monocarpellary pistil such as those of *Crotalaria verrucosa, Cæsalpinia pulcherrima* and *Tephrosia purpurea* open along both the sutures, namely, ventral and dorsal. These fruits are called **legumes** (Fig. 125). Most of the plants of the family Leguminosæ have this kind of fruit, namely, legume. In some Leguminous plants the fruits split transversely into one seeded pieces. This kind of fruit is termed a **lomentum.** Fruits of several species of *Acacia, Desmodium* and of *Mimosa pudica* are lomenta.

(ix) **Capsule.**—A syncarpous many seeded dry fruit is usually dehiscent, and it is called a capsule. It may consist of two or more carpels, and it may be unilocular or multilocular (Fig. 126).

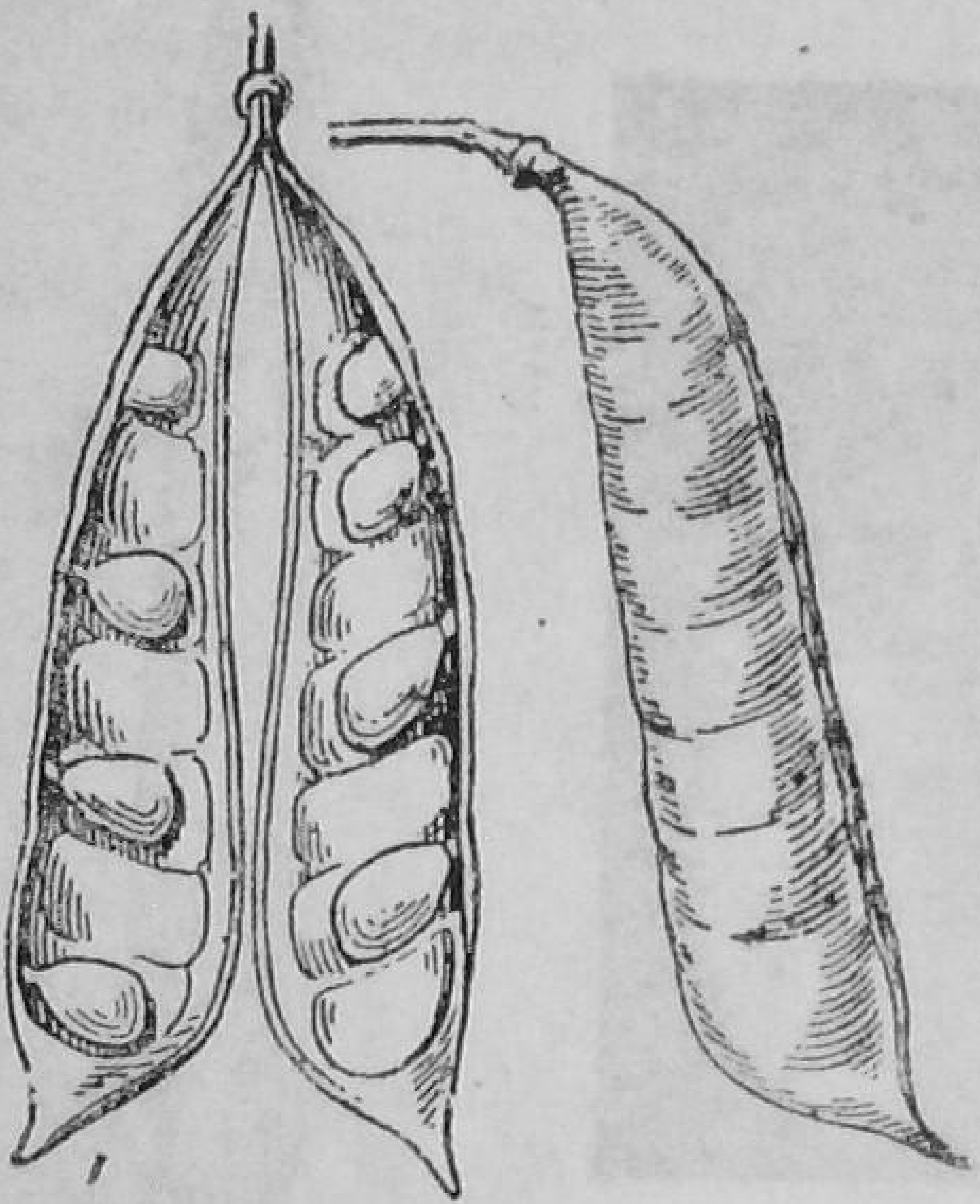


Fig. 125. Legume of *Cæsalpinia sepiaria.*

A unilocular capsule with parietal placentas may have only pores at the top of the fruit, or may open by valves to liberate the seeds. The fruit of *Papaver* possesses pores at the top of the capsule and seeds escape through them. In the fruit of *Argemone* we find valves only at the top but not extending to more than about one fourth of the length of the fruit. The fruit of *Ionidium* splits down to the base into three valves, and in this case each valve represents the halves of two contiguous carpels and is placentiferous in the middle.

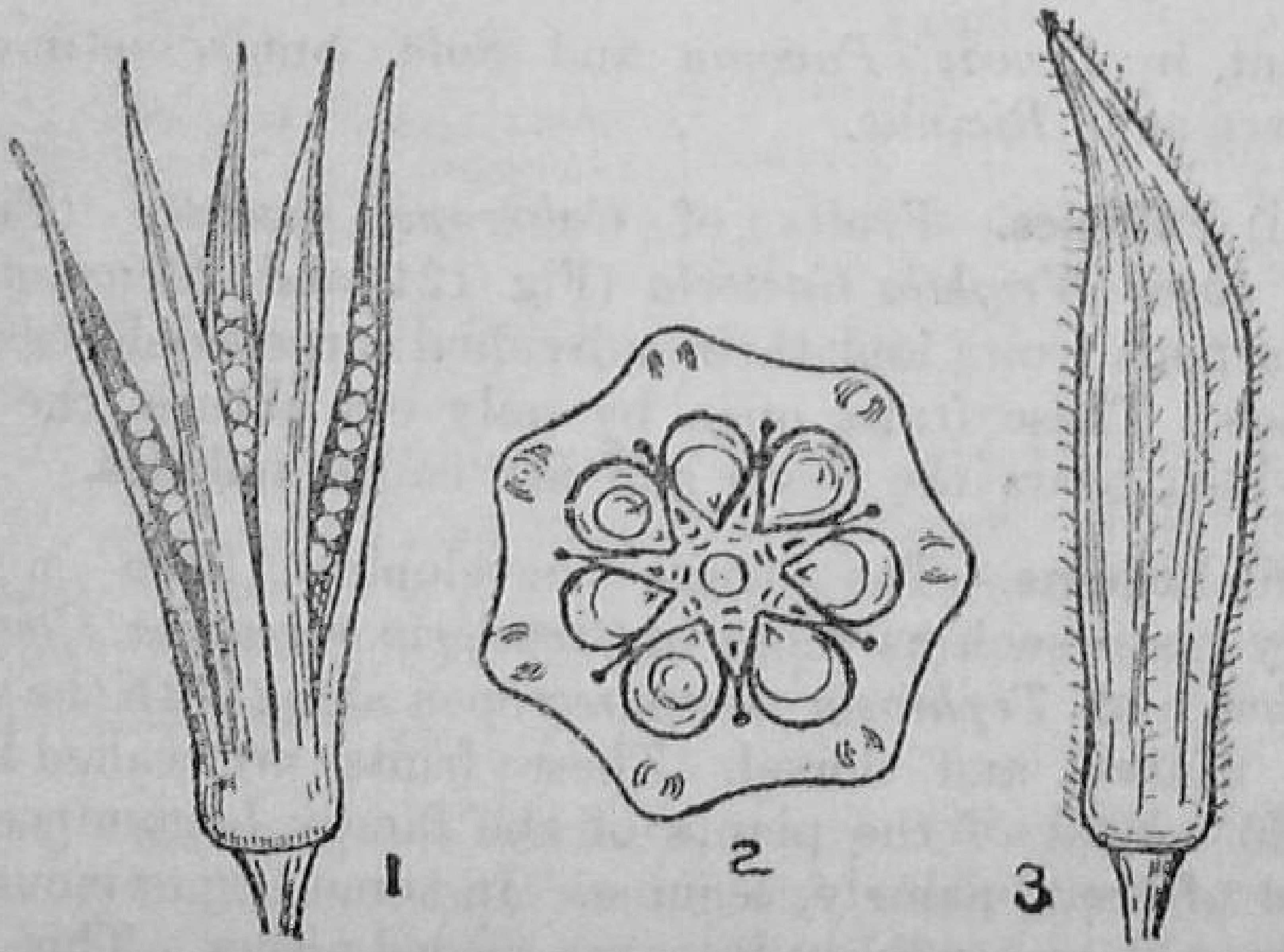


Fig. 126. Capsule of *Hibiscus esculentus.* (1) dry fruit burst open ; (2) transverse section of green fruit. (3) green fruit.

Usually multilocular capsules with axile placentation open longitudinally either along the back of the carpels between the partition walls of the locules, as in *Hibiscus esculentus* (Fig. 126), or they dehisce along the lines of the junction of the carpels, splitting each of the septa into parallel plates and separating the carpels from one another. The former mode of dehiscence is called the loculicidal and the latter septicidal (Fig. 109). In loculicidal dehiscence seeds are exposed immediately after dehiscence, whilst in septicidal dehiscence each separated carpel has to dehisce along the ventral suture to liberate the seeds. Further, the segments of the capsule after dehiscence correspond to the carpels in septicidal dehiscence, but those resulting from loculicidal dehiscence do not correspond to them. Each segment consists of one half of each of the two contiguous carpels. In some capsular fruits the pericarp breaks away from the septa, leaving them as a column in the centre. Then the dehiscence is **septifragal.** According to the position of the septa with reference to the pieces of the pericarp we may distinguish two kinds of septifragal dehiscence. When the septa are exactly opposite to the middle of the pieces of the pericarp they are **loculicidally septifragal,** and if the septa are opposite the opening they are **septicidally septifragal** (Fig. 128).

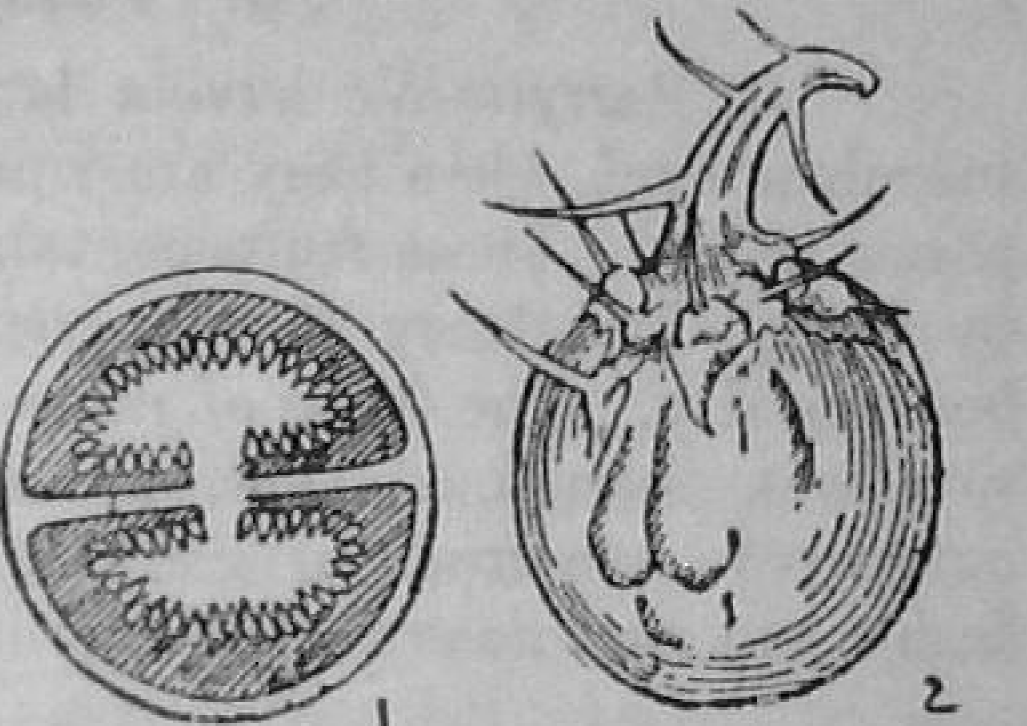


Fig. 127. Berry of *Solanum.* (1) berry cut across: (2) full berry.

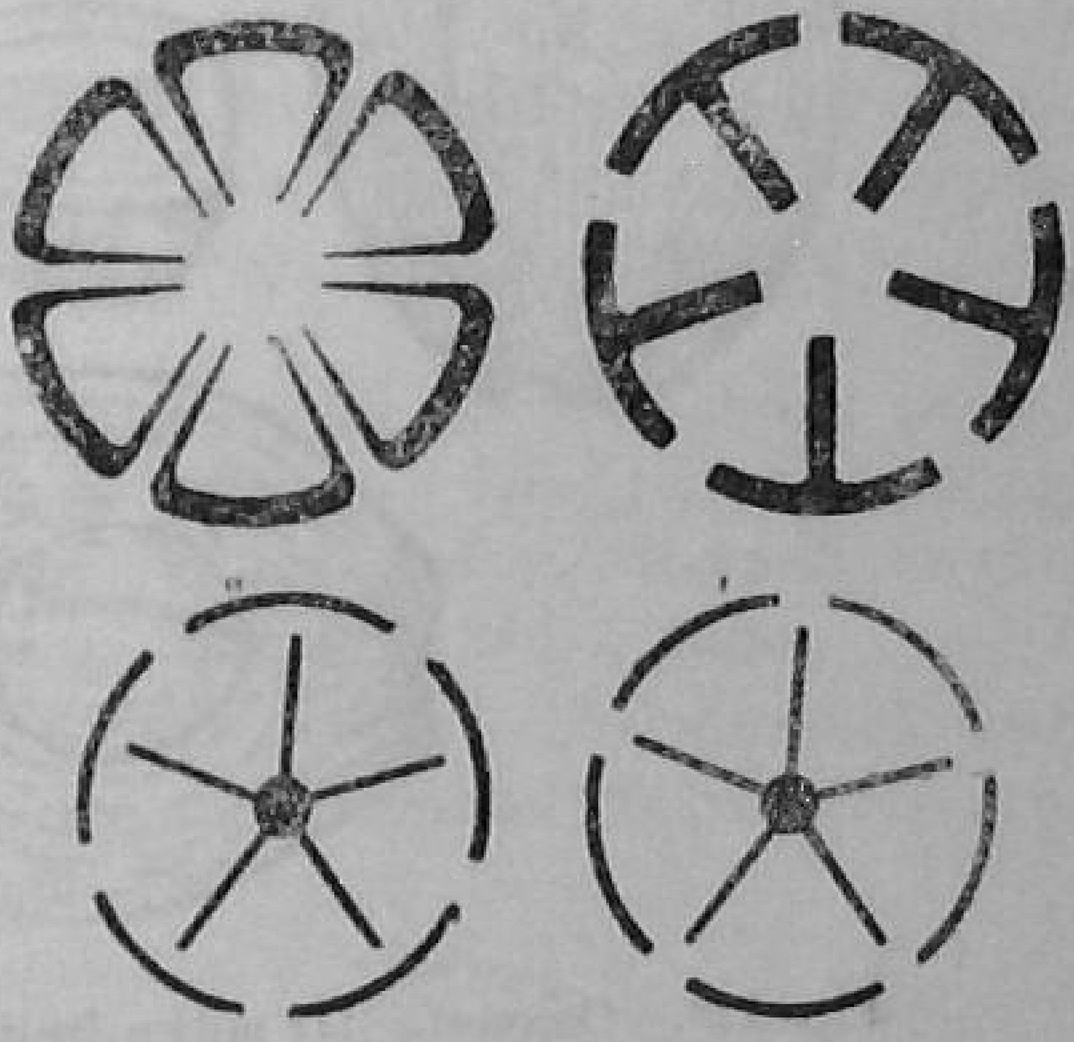


Fig. 128. Diagram of septicidal and loculicidal dehiscence (top) and loculicidally septifragal and septicidally septifragal dehiscence (bottom).

(x) **Siliqua.**—The fruits of many of the plants of the family Cruciferæ are bicarpellary fruits with a false partition dividing the locule into two cavities. There are two parietal placentas and the walls of the loculi break away from the false septum and the placentas, from below upwards. This kind of fruit is called the siliqua.

(xi) **Pyxidium.**—In *Portulaca* the fruit opens by a transverse-lid and this kind of fruit is called a pyxidium

B. Fleshy Fruits.

(i) **Berry.**—We have a large number of fruits which are succulent even when they are ripe and ready to fall off from the parent plant. These fruits contain several seeds and they escape by the gradual decay of the pericarp when it is fleshy or after it becomes dry. The fruits of grape-vine, guava, *Solanum* (Fig 123) tomatoes, mango, almond, pears and apples are fleshy. The pericarp in the fruits of guava, grape, tomato, and *Solanum* is fleshy and succulent throughout its thickness and when ripe the

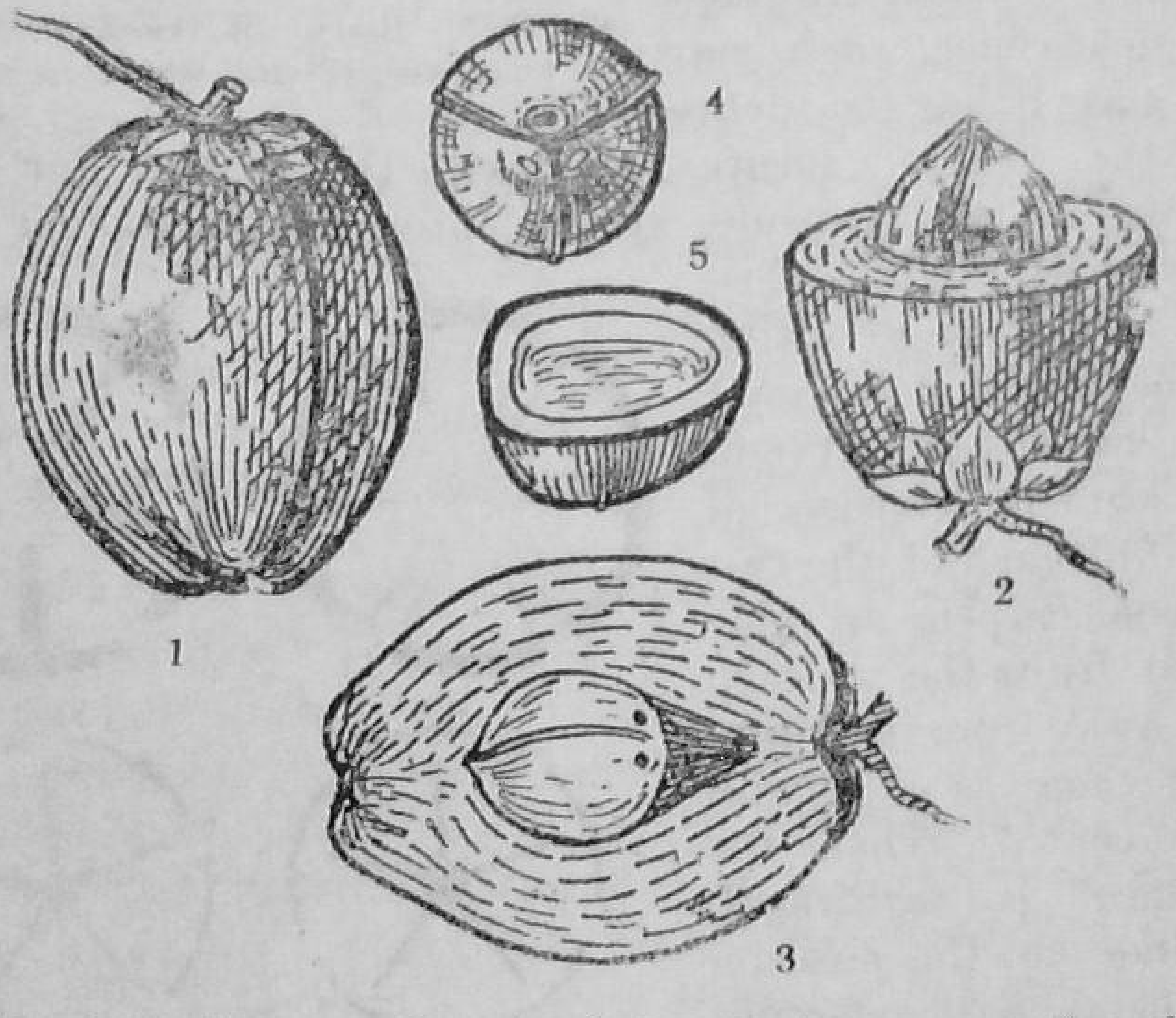


Fig. 129. Coconut. (1) entire fruit. (2) transverse section of fruit showing a portion of the nut. (3) longitudinal section showing the nut. (4) and (5) views of nut.

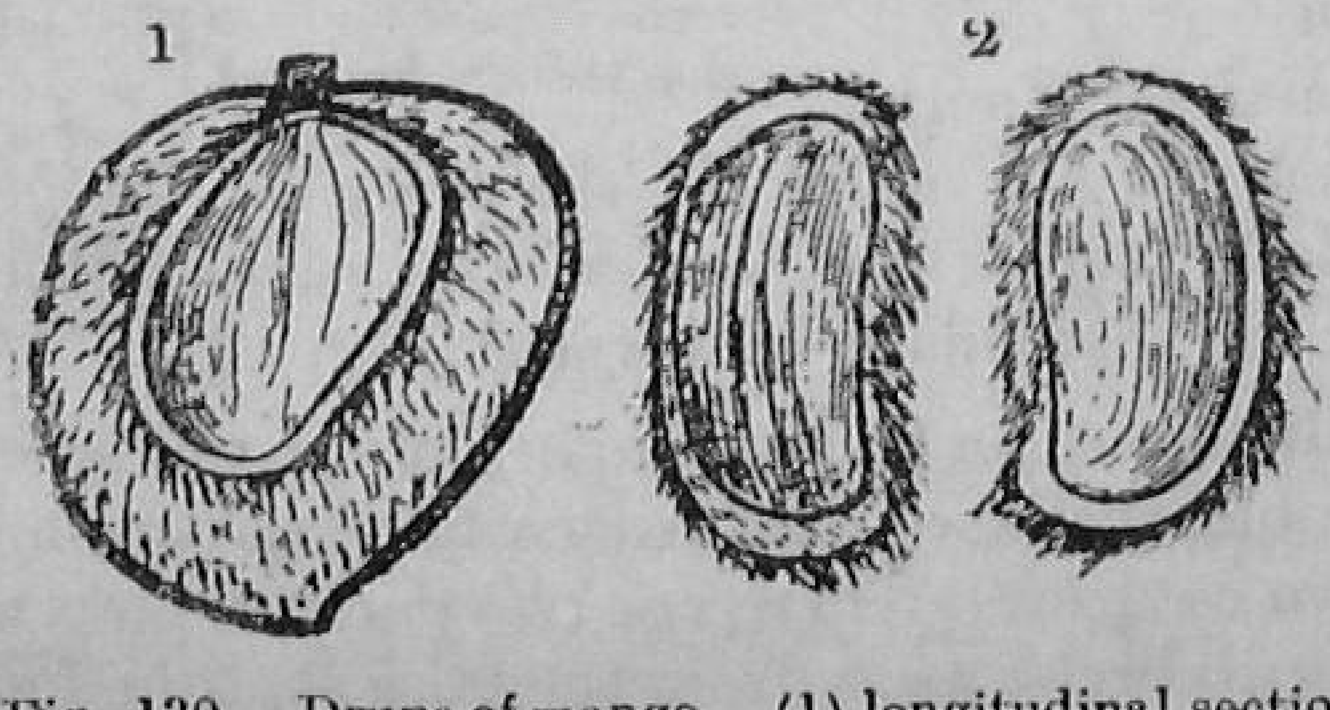


Fig. 130. Drupe of mango. (1) longitudinal section; (2) and (3) portions of the hard endocrap.

fruit becomes pulpy. In the fruits of *Solanum* and in guava the pulpiness is due to the pericarp and the placentas becoming fleshy. In tomatoes the pulp is contributed by the pericarp, placentas and seed coats. All fruits in which the whole of the pericarp is more or less succulent and not hardened are called berries. Generally berries have many seeds, but we have also one seeded berries such as the date and the chow-chow fruit (*Sechium edule*) In some fruits the pericarp is fleshy at one stage and later on it dries up as in *Capsicum*.

(ii) **Hesperidium.**—In some fruits the pericarp is not very fleshy but somewhat firm and leathery in consistency, as in orange and pomelo. In these fruits the pericarp shows a certain amount of differentiation. We can distinguish three distinct parts, namely the outer glandular aromatic portion or the epicarp, the somewhat whitish spongy portion or the mesocarp and the inner portion or the endocarp covered with watercells which extend to the seeds. Fruits of this kind are called **hesperidiums.**

(iii) **Pepo.**—We have another kind of fleshy fruit in plants of the family *Cucurbitaceæ* composed of three to five carpels forming a single cavity with very fleshy seedbearing placentas. These fruits are inferior and the pericarp is united to the receptacular tube and is very hard and bony. These fruits are termed pepos.

(iv) **Pome.**—The pears and apples are also fleshy fruits, but the fleshy part is only the thalamus. The pericarp forming the five cells is hard, parchment like and united externally to the receptacular tube. This kind of fruit is called a **pome.**

(v) **Drupe.**—Some fruits have pericarps fleshy outside and hard and stony inside, as in mango and *Zizyphus*. Such a fruit is a **drupe.** In drupes like mango the epicarp is thin and membranous, the mesocarp is fleshy and the endocarp becomes a hard shell. The coconut is also a kind of drupe. (Fig. 129). The green or brownish external part is the epicarp, the middle fibrous part the mesocarp, and the shell the endocarp. The kernel is really a seed consisting of a hollow endosperm filled with water. In mango there is a single seed and it is enclosed by the shell, and in Zizyphus (Fig. 131) the shell encloses two seeds.

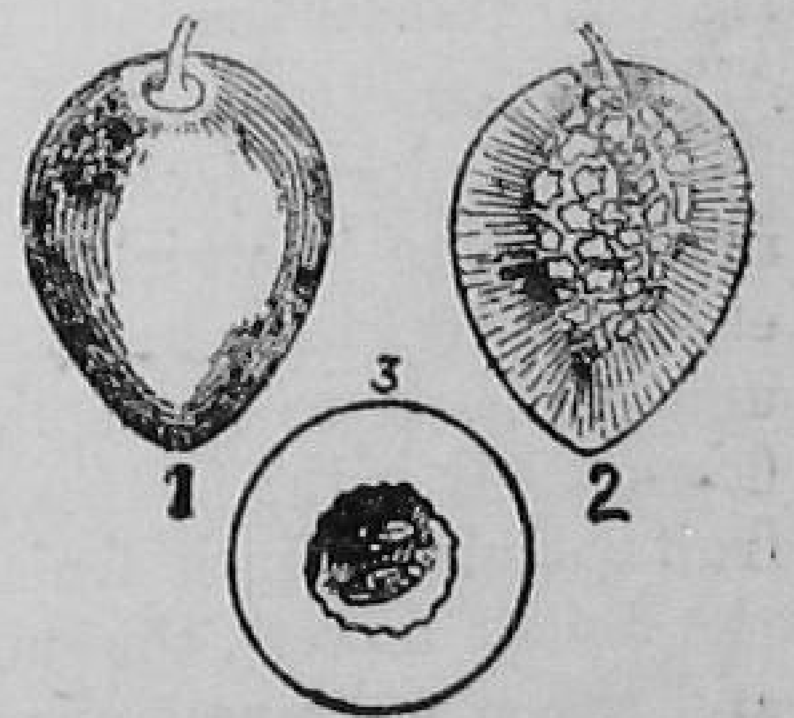


Fig. 131. Drupe of *Zizyphus* (1) entire fruit (2) longitudinal section of the fruit showing the hard endocrap (3) transverse section of the fruit.

(vi) **Pyrenes.**—In some plants, as in *Vitex* and *Duranta* the seeds are enclosed by separate bits of shells, instead of being enclosed by one shell. These are really **drupelets** and are sometimes called **pyrenes.**

Aggregate Fruits

We have already said that an apocarpous fruit developed from a single flower is termed an **aggregate** fruit. The fruits of *Rananculus, Clematis, Naravelia* are aggregate fruits consisting of indehiscent dry carpels or achenes. The aggregate fruit of *Miehelia Champaca* and fruits of many Asclepiadaceæ have dehiscing carpels which we have called follicles. In the fruits of Raspberry and *Polyalthia* the carpels are fleshy, and they are drupelets in the former and berries in the latter.

Multiple Fruits

We have lastly to consider **composite** or **multiple** fruits formed from the development of the whole of the inflorescence. In *Dorstenia indica* the fruits are very small and they are imbedded in a flat disk, which is really the receptacle. This is called a **coenanthium** (Fig. 132). In several species of *Ficus* what is called the fruit or fig is merely the hollow receptacle bearing unisexual flowers, inside on its surface. This is termed a **fig, syconus, syconium** or **hypanthodium** (Fig. 133).

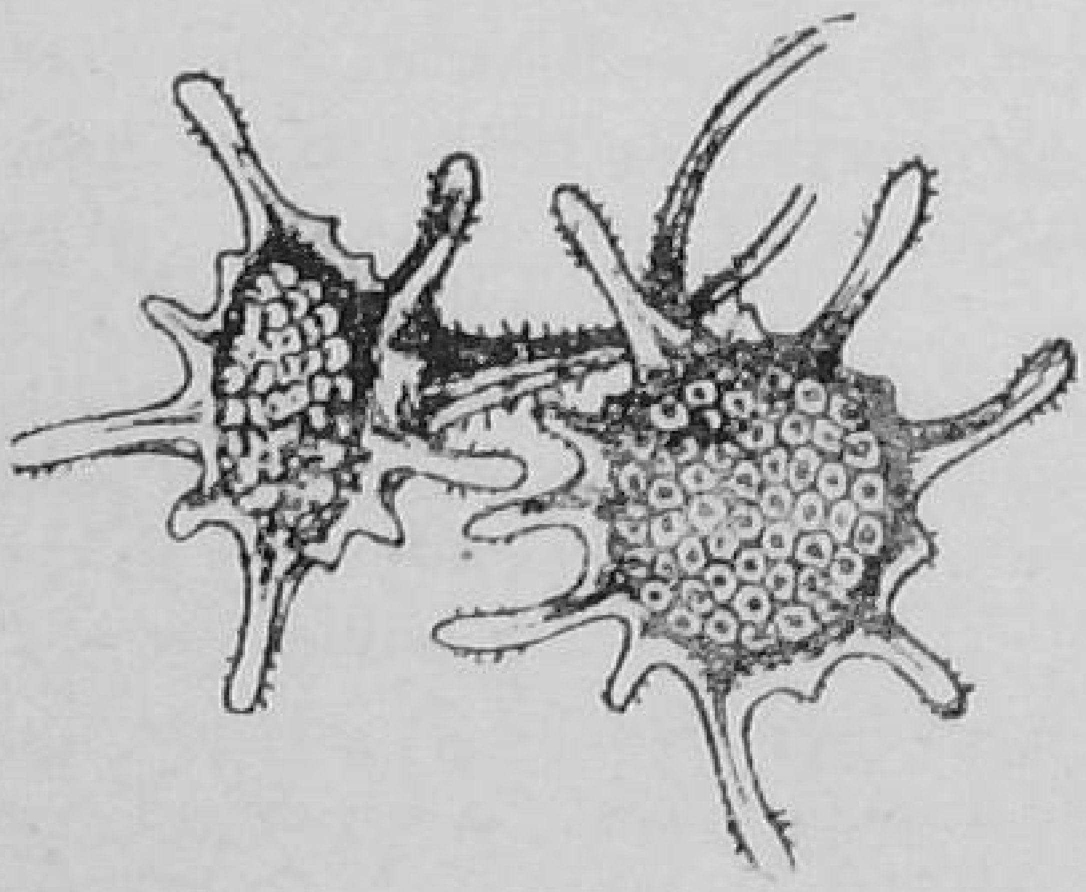


Fig. 132. Coenanihium of *Dorstenia indica.*

The fruits of jack and pine apple (Figs. 134 & 135) are also inflorescences in which the rachis of the inflorescence and parts of the flowers have become fleshy. In the jack the flowers are unisexual and so the spikes are either of male flowers or female flowers. It is the female spike that develops into the composite fruit called the jack fruit. The edible flakes in this are really the female flowers, the succulent sweet portion being the perianth and the membranous bag enclosing the seed being the pericarp. The coarse filaments between the flakes are undeveloped female flowers. In the pine apple the fleshy part consists of the rachis and the lewer portions of the flowers. The polygonal areas appearing externally correspond to the flowers and in them the

remains of bracts and other parts of flowers are often visible (Fig. 135)

There are also instances of fruits in which the fleshy part does not belong to any part of the fruit proper. For example, the fleshy portion in the cashew-nut though called a fruit, is only the pedicel which has become fleshy (Fig. 136). So this is a false fruit. The real fruit is the nut at the free end of the peduncle.

As already stated in the earlier part of this chapter, other portions besides the gynæceum become modified and form part of what is called the fruit. In strawberry the fleshy part is the thalamus swollen and the so-called seeds are all small carpels

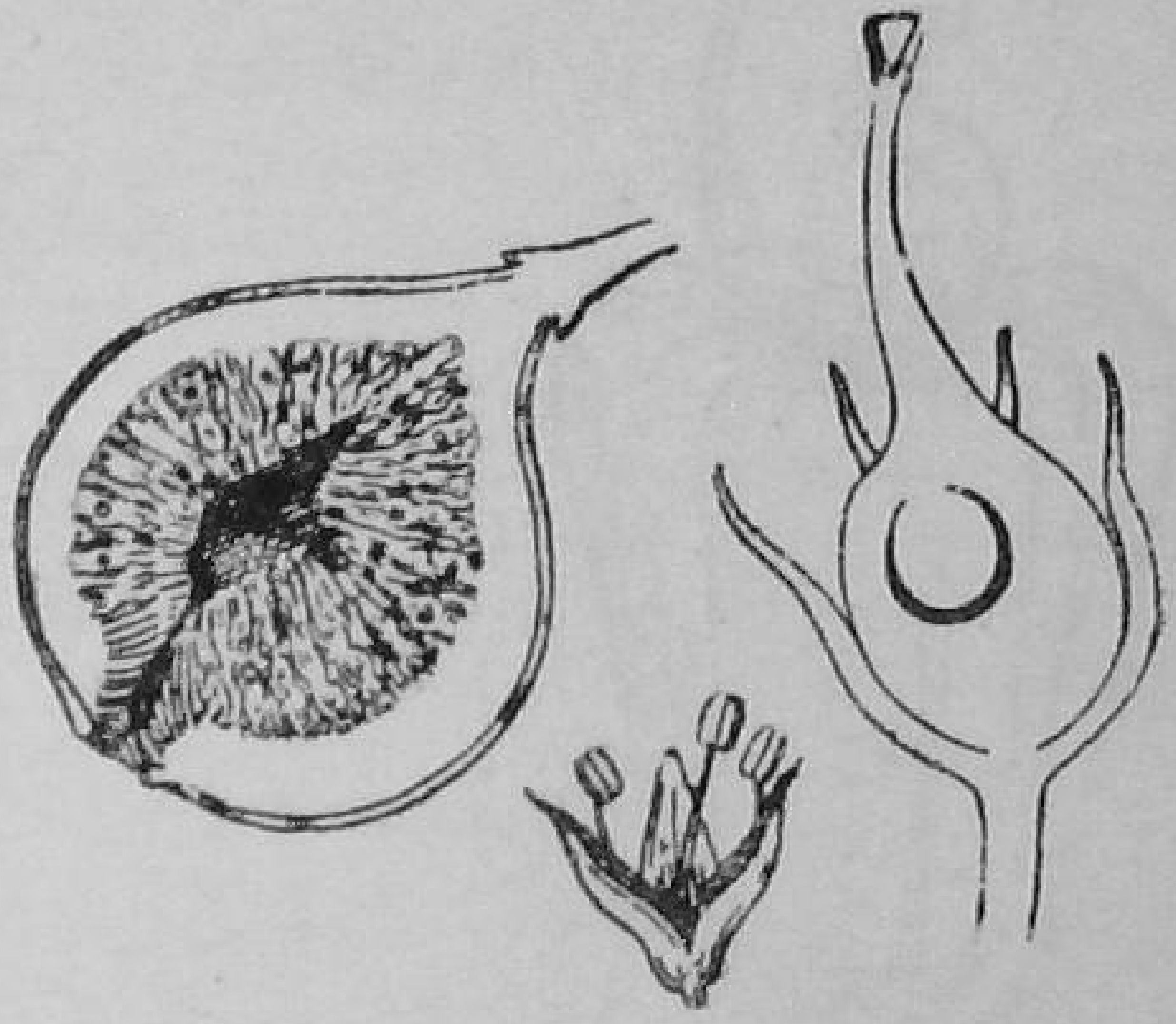


Fig. 133. Fig or syconus.

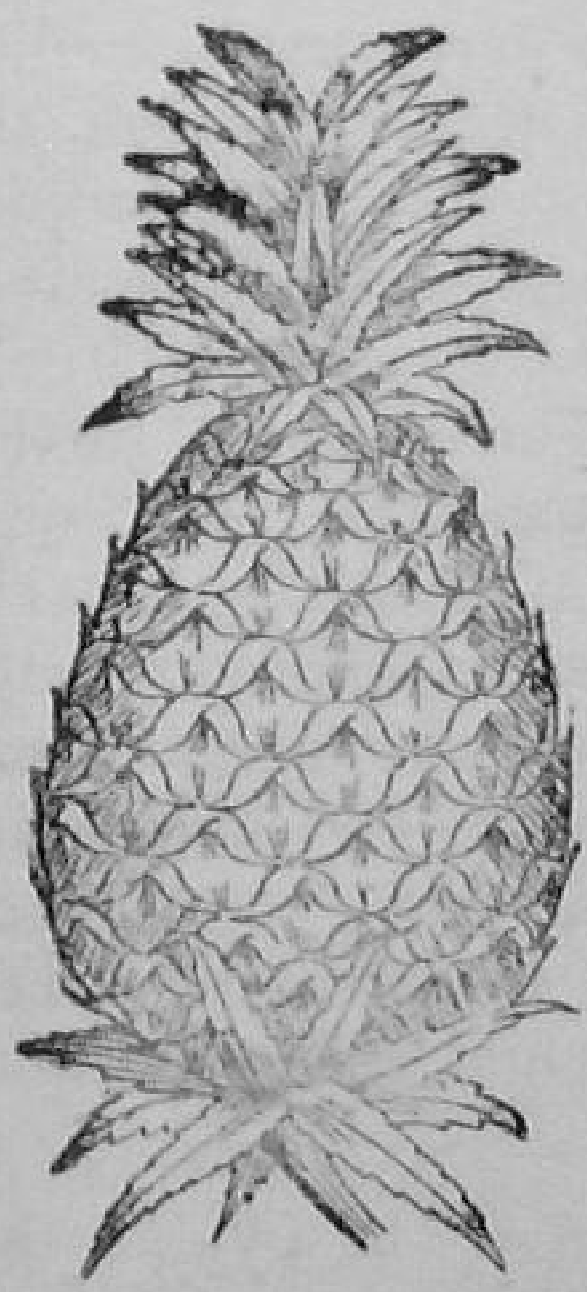


Fig. 134. Pineapple.

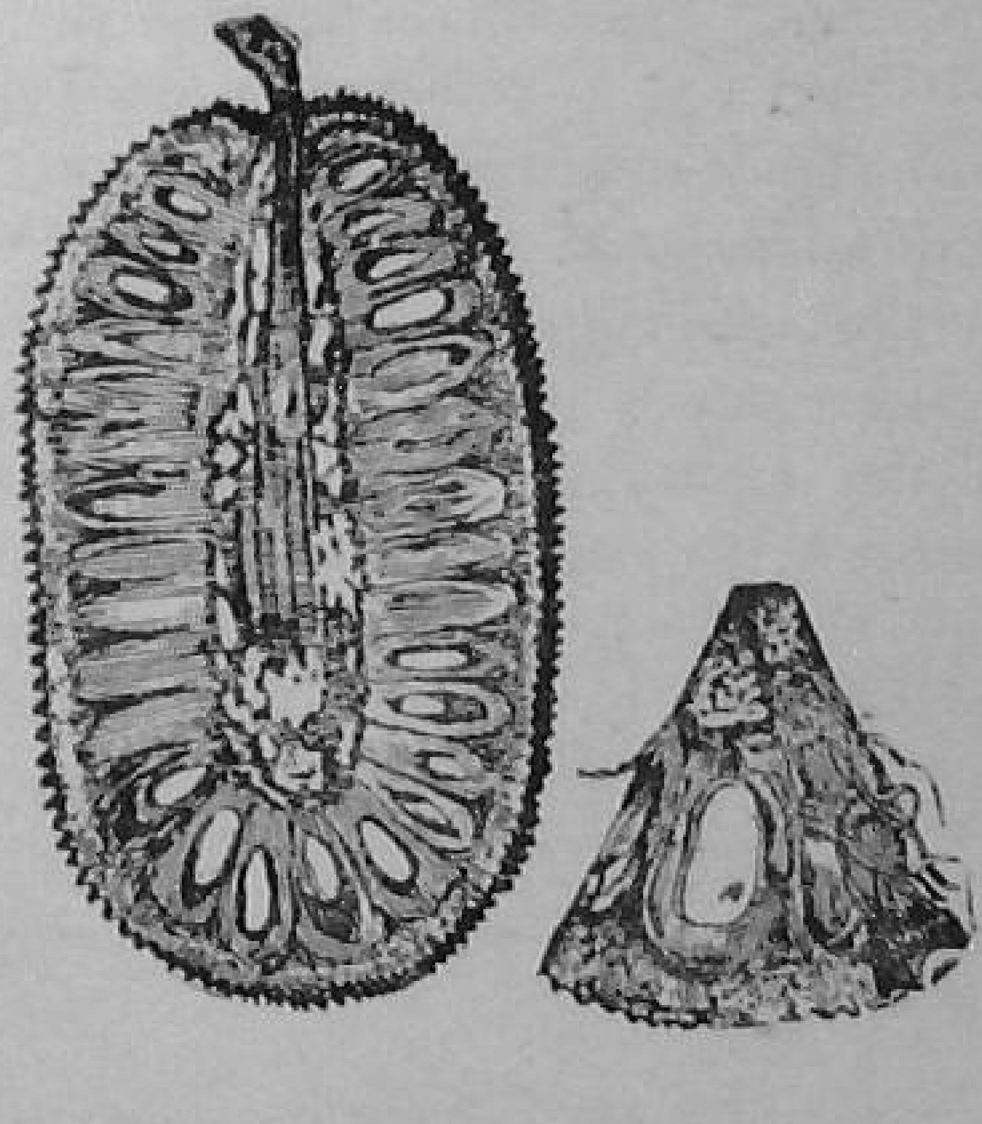


Fig. 135. Jack fruit.

embedded on the surface of the fleshy thalamus. In *Nelumbium speciosum* the top shaped fruit is really the thalamus expanded

and the so-called **seeds** are really ripe **carpels embedded on the** top of the thalamus.

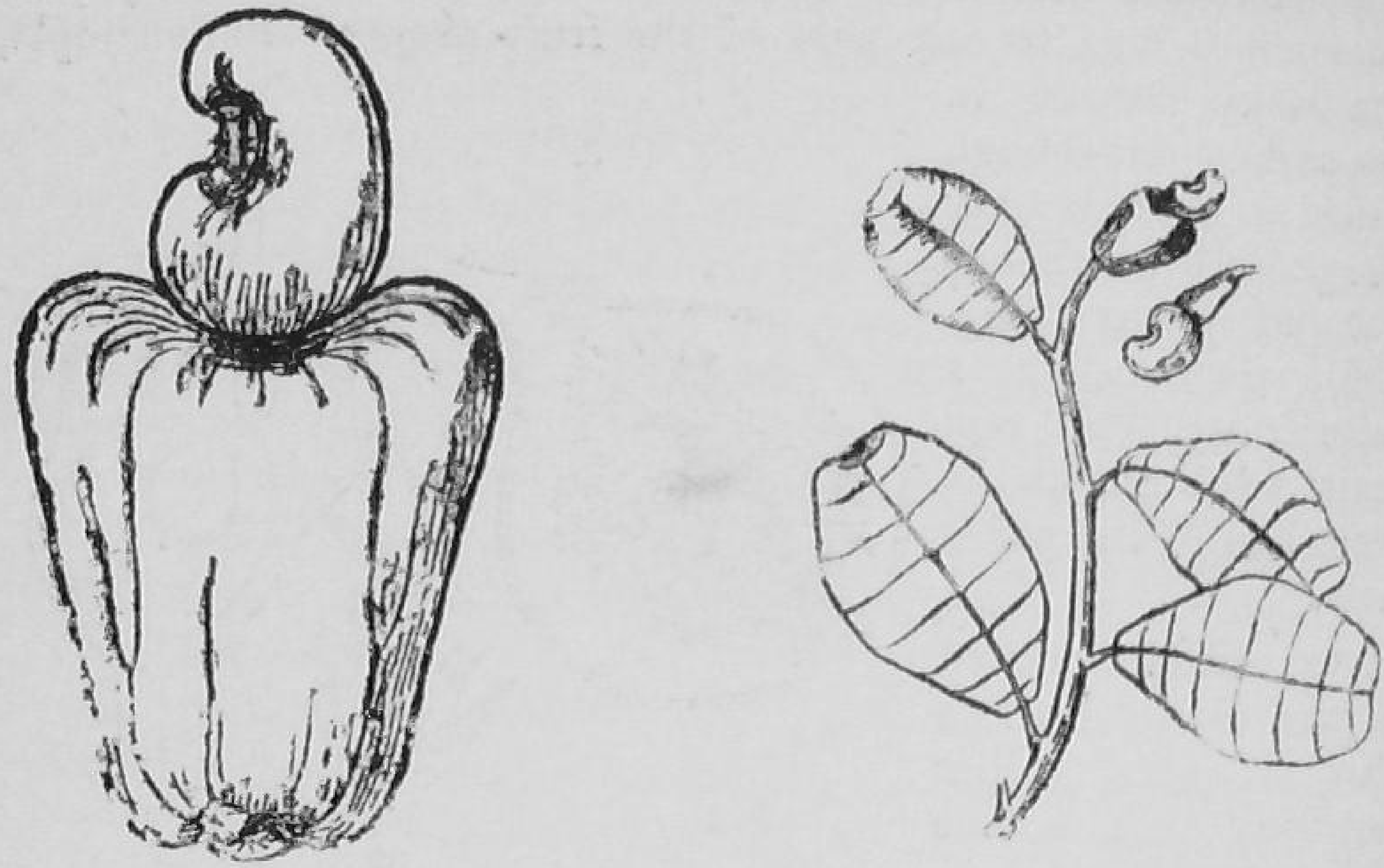


Fig. 136. Cashew-nut **fruit** (left); branch of cashew-nut with fruit (right)

THE SEED

The Development of Seed.—The process of **fertilisation** or **syngamy** refers to the fusion of the male nucleus in the pollen tube with the female nucleus in the egg. After fertilisation, the fertilised egg is referred to as **Zygote.** The zygote now contains 2n number of chromosomes while the pollen and the egg contained n number each. The zygote forms a wall layer round itself. It divides into cells, the upper and the lower. The upper cell further divides into a layer of cells and forms the **suspensor.** The lower is the **embryonic cell.** The suspensor functions for some time and it helps the embryo to draw the food material from the nucellus and this feeds the growing embryo The embryonic cell forms into 8 cells by three divisions. It then divides periclinally and forms the wall layer. The four inner cells lying near the suspensor develop into radicle and hypocotyl; the four lower cells away from the suspensor develop into plumule and cotyledons. (Fig. 137).

In the seed we recognise all the parts of the ovule; they are only considerably modified. The seed coats, testa and tegmen, are derived respectively from the outer and the inner integuments. The cells of the outer integuments are thin walled, but when it changes into the testa, the cell walls become thickened by suberisation and lignification, because it has to serve as an effective

organ against drying and injury of the young plant. In some seeds, as in mustard and linseed, the epidermis of the seed-coat becomes mucilaginous, and this helps in retaining water and also serves as a means of fixation to the soil. Seeds of *Acanthaceous* plants have hairs growing out from the epidermal layers and these also are mucilaginous and help in fixation to the soil. In

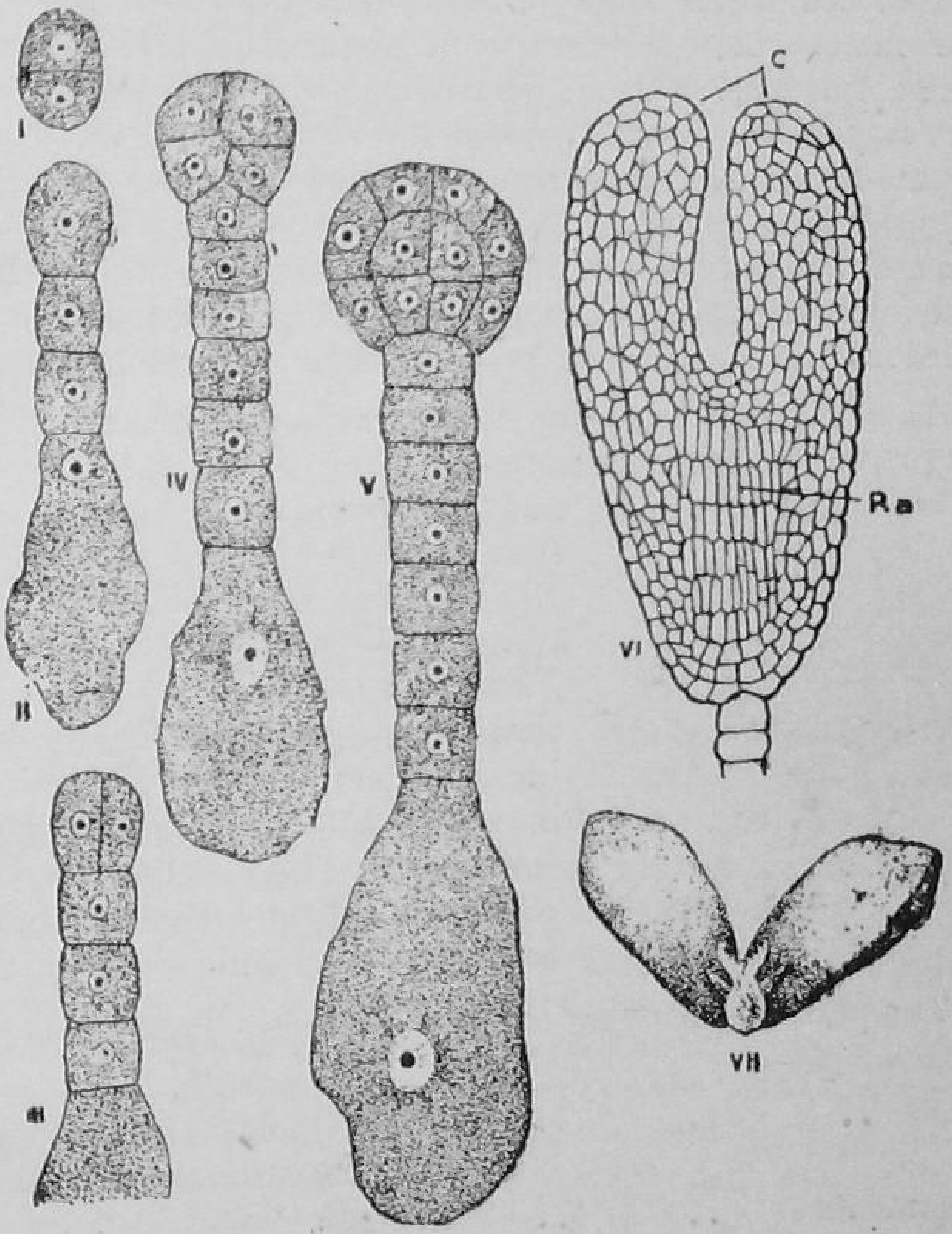


Fig. 137. Development of seed. (i) Zygote dividing into upper and lower cells. (ii) formation of suspensor and embryonic cell. (iii) & (iv) division of embryonic cell into a group of 8 cells. (v) periclinal division and formation of wall layer. (vi) formation of plumule and cotyledons at the upper and the hypocotyl and radicle at the lower end.

the seed coat, we also find the micropyle, the hilum, and raphe in anatropous seeds. All these are parts present in the ovule even before fertilisation.

The embryo and the endosperm that are formed within the embryo sac as the result of fertilisation are really newly formed

parts. In all seeds endosperm is formed and it persists within the embryo sac in some seeds and in others it disappears with the growth of the embryo. Those seeds in which the endosperm persists are called **endospermous** or **albuminous** seeds, and seeds in which they do not persist are **non-endospermic or ex-albuminous** seeds. In the case of non-endospermic seeds the endosperm gets absorbed by the embryo, and finally the cotyledons become larger on account of the transfer of material from the endosperm to the cotyledons. This transfer of material from the endosperm to the cotyledons becomes obvious if we examine the seeds of some leguminous plants in the course of development. In partially developed seeds of *Dolichos*, *Crotalaria* and *Cæsalpinia* we find the small cotyledons embedded in a fleshy mass which is very massive in very young seeds, and it gradually decreases and the cotyledons increase in size proportionately as the seed grows.

As a rule, the nucellus tissue gradually decreases as the embryo and the endosperm are developed within the embryo sac, and finally when the embryo is fully formed the whole of it disappears. But however, in a few seeds, such as those of *Piper*, *Nymphæa*, *Canna* and *Elettaria Cardamomum*, the nucellus tissue persists and we find it occupying considerable space within the seed between the seed coat and the embryo-sac. This nucellus tissue in the seed is called the **perisperm**, and seeds having it perispermic seeds (Fig. 132).

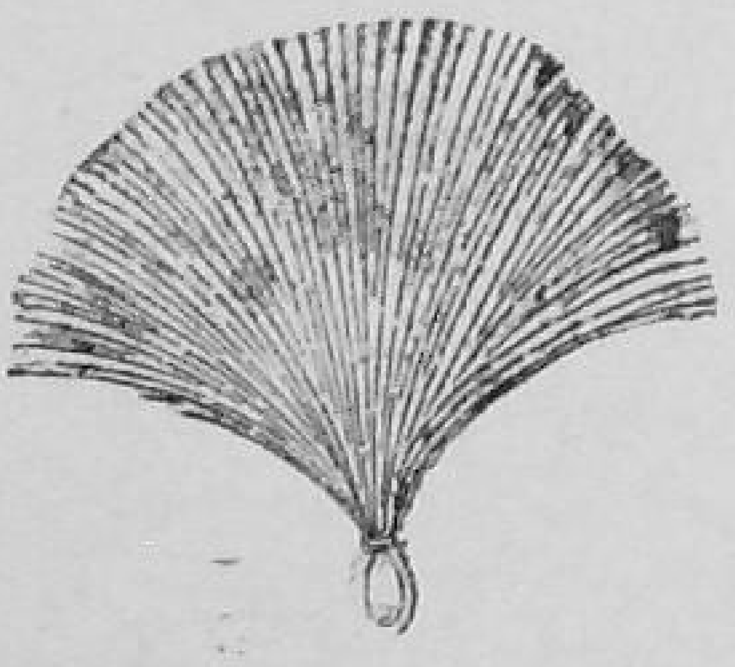


Fig. 138. Comose seed of *Calophyllum*

The parts of the ovule and the seed are compared below :—

Ovude.	Seed.
Funicle	Stalk (In some cases may persist as raphe caruncle or aril).
Integuments	Seed-coats.
Hilum	Hilum.
Micropyle	Micropyle.
Nucellus	Perisperm (when persistent).
Egg cell	Embryo (*i. e.* Primary axis and cotyledons).
Secondary nucleus ..	Endosperm and not present in seeds.
Snyergids and antipodals ..	Disorganised and not present in seeds.

Seeds also show variations. They are multifarious in their form, i.e., they may be round, oval, flat, cylindrical and angular The seed coat may be smooth, wrinkled, furrowed, ribbed, tubercled or reticulate. It may have hairs or wings as outgrowths. In the seeds of Asclepiadeæ hairs occur as a tuft at the pointed end. Such seeds are called **comose** seeds (Fig. 138). In some seeds, as in those of *Alstonia*, tufts of hairs are found at both the ends of the seed. Hairs are found all over the surface of seeds *Hibiscus micranthus* and *Cochlospermum gossypium*. In some seeds such as those of *Dolichandrone*, *Tecoma*, *Oroxylum* and *Cedrela*, out-growths take the form of wings. In many a seed the testa is hard and shell like especially where protection is not afforded. If the seeds are well protected by a hard pericarp, the seed coats remain thin. In some seeds even the seed coat is not present, as in *Crinum* seeds.

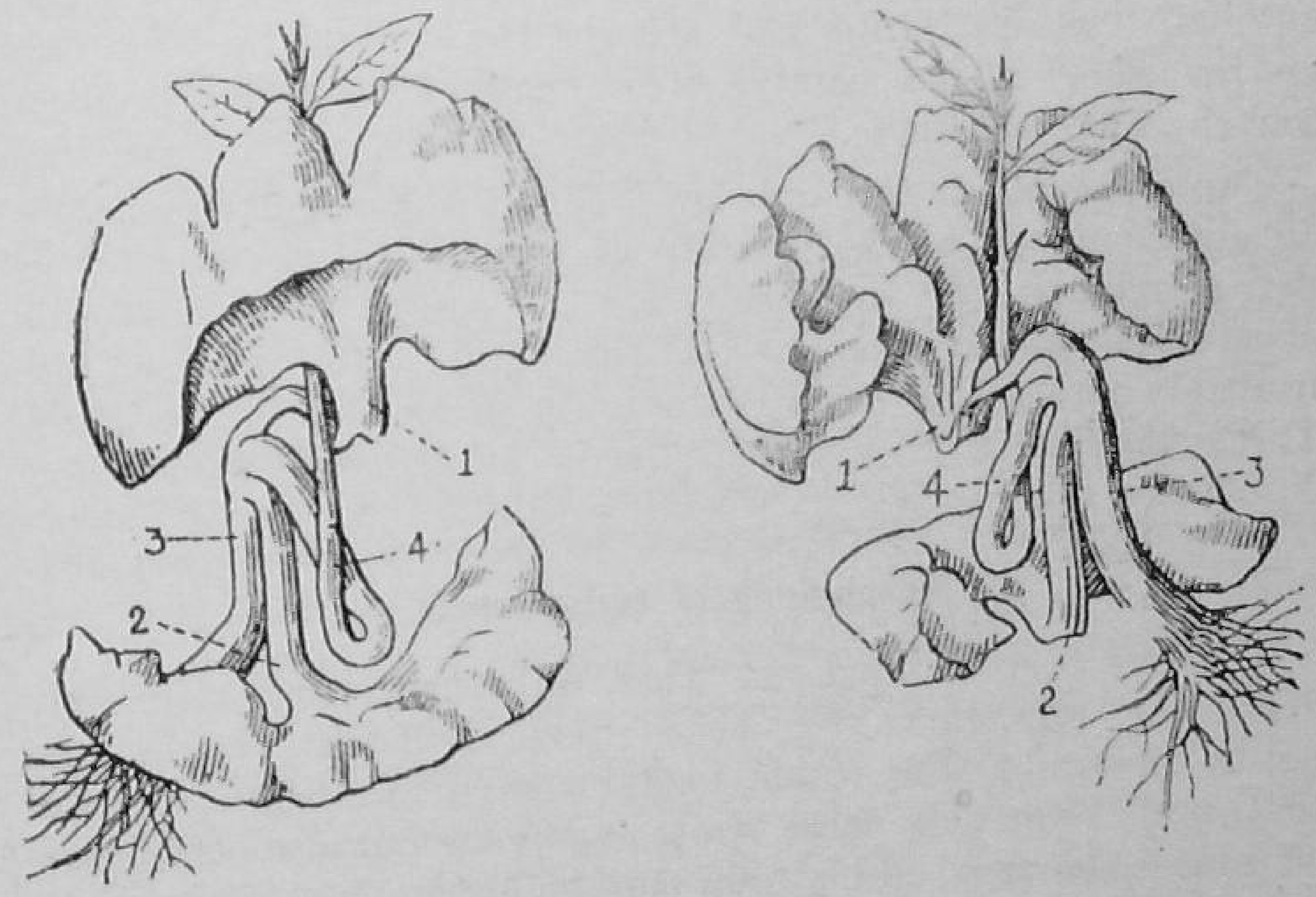


Fig. 139. Lobed Cotyledons of *Vateria indica*. (1) and (2) Cotyledons. (3) hypocotyl. (4) plumule developing into a shoot.

Sometime we find outgrowths merely covering the seeds without adhering to the seed coats. Such outgrowths usually arise from the funicle or from the micropyle and they are called arils. In the seeds of *Nymphæ* and in those belonging to the family, Passifloreæ, the arils grow out from the funicle, and they are micropylar in origin in *Myristica* and *Pithecolobium dulce* (Fig. 143). If the outgrowth is small as in the seeds of *Polygala*

it is called a **strophiole.** In castor seed it is termed a **caruncle** and in *Myristica* as **mace.**

In the embryo the primary axis is well differentiated into the plumule and the radicle in many seeds, and in some seeds even leaves can be seen in the plumule. This differentiation is not patent in a few seeds. The cotyledons may be thick or thin and leaf like.

The two cotyledons may be similar and equal or they may be unequal, as in *Artocarpus integrifolia* and *Hopea parviflora.* We find the cotyledons irregularly lobed in the seeds of *Vateria indica* and cotton (Fig. 139). In monocotyledonous seeds, there is only one cotyledon and it is clearly distinguishable in many seeds. In some seeds it is not distinguishable. For instance, in the coconut, date and the seeds of some other palms the embryo is usually small and cylindric without any differentiation. But as germination progresses, the cotyledon (or haustoria of some authors) develops, grows and absorbs the endosperm, by filling up the whole of the cavity. This enlarged cotyledon is often spoken of as " the apple."

In a few plants the seeds are enclosed permanently and they do not come out of the pericarp or other envelopes even when they germinate. All such fruits are one seeded. The caryopsis of cereal plants and achenes are of this nature. In some seed like fruits the external covering is the lower portion of the perianth. This is the case in the so-called " seeds " of *Mirabilis*, *Pisonia* and *Bœrhaavia.*

Morphology of edible parts.

It has been pointed out that all animals are ultimately dependent on plants for their food. Different cereals and pulses constitute the staple food for man in different parts of the world. Not only these fruits and seeds but also other parts of plants become edible due to the stored food or aromatic principles contained in them. The following are a few examples to indicate the morphology of such edible parts.

1. **Tuberous Roots.**—Radish, beet, carrot, knol-kohl, turnip, tapioca and sweet potato.

2. **Stems.**—Tuber in potato; corms in yam and colocasia; rhizomes in ginger and turmeric.

3. **Bulbs.**—The fleshy leaf bases of onion and garlic.

4. **Leaves.**—Amaranth, spinach, cabbage, brussels sprouts, coriander, murraya.

5. **Flowers.**—Cauliflower, agathi, rose, neem. In the case of *Musa*, the flowers as well as floral axes are edible.

Fruits.—When the fruit develops, different parts of it become edible because of the reserve food in them. Therefore the morphology of the edible part may vary in different fruits. The following examples will illustrate this statement.

(1) In Cashew nut, the thalamus swells up and is fleshy. The real fruit, which is a nut is situated at the top of this swollen thalamus. In the case of apple, pear and other pomes, the thalamus grows round the ovary and is juicy and edible. The real fruit situated in the centre is made up of achenes.

(2) In the case of some multiple fruits such as Pineapple, the central axis of the inflorescence also becomes partly edible. In the mulberry also, the catkin including the central axis is edible.

(3) In fig the thalamus is fleshy and forms the hollow cup containing the flowers. The entire structure is edible.

(4) In the case of all fruits developed from inferior ovary, (Rosaceæ, Myrtaceæ, Cucurbitaceæ), the thalamus forms a deep cup inside which the pistil is placed and the walls of the cup grow fused with the carpels of the pistil. Therefore, in the fruits such as guava, gourds and plantains the carpel as well as the fused thalamus become edible. In the case of ripe banana, this portion is peeled off partly and the fleshy carpel is edible.

(5) In the case of accrescent calyx, it may become edible, e.g., the Gogu (*Hibiscus cannabinus*) and the brinjal, where it is not uncommon to cook the accrescent fleshy calyx.

(6) In the case of jack fruit the perianth becomes fleshy and encloses the fruit inside. The spiny projections on the multiple fruit are formed by the tips of sterile flowers. The edible portions are the fleshy perianth and the seeds.

In many other common fruits used as vegetable, such as cluster-bean, bendai and drumstick the ovary develops into the fruit and thus the pericarp and the tender seeds inside are wholly edible. In some instances the pericarp may become distinguishable into epicarp, mesocarp and endocarp. For example, in drupes such as mango the epicarp forms the skin layer, the mesocarp is fleshy and edible while the endocarp becomes stony enclosing the seed inside.

In oranges, the epicarp is glandular and aromatic, the mesocarp is whitish and spongy and the endocarp is covered with water cells. These are the glandular hairs of endocarp which are juicy and edible.

Edible parts in seeds.—In the case of *Pithecolobium dulce* and *Myristica fragrans* (mace) the arils on the seed become edible. In pomegranate, the fleshy **testa** is edible.

In all cereal grains such as maize and rice, it is the endosperm that is valued for the starch in it. The germ or the embryo and the aleurone layer or the bran also contain very valuable vitamins and proteins. In the coconut, the endosperm or the kernel is the edible part and the embryo which is insignificant is embedded at one end of it. In the case of palmyra fruit, the ripe fruit contains fleshy matter in its fibrous mesocarp. Some people relish this. When the fruit is tender, the watery or fleshy endosperm is taken and relished much in summer months. Sometimes, the seeds are germinated and in the seedling, the first leaf which is fleshy and starchy is boiled and eaten.

Thus it may be seen that different parts become edible in different plants.

Dispersal of fruits and seeds.

Flowering plants have a tendency to produce as many seeds as possible. This production of seeds in large numbers is an

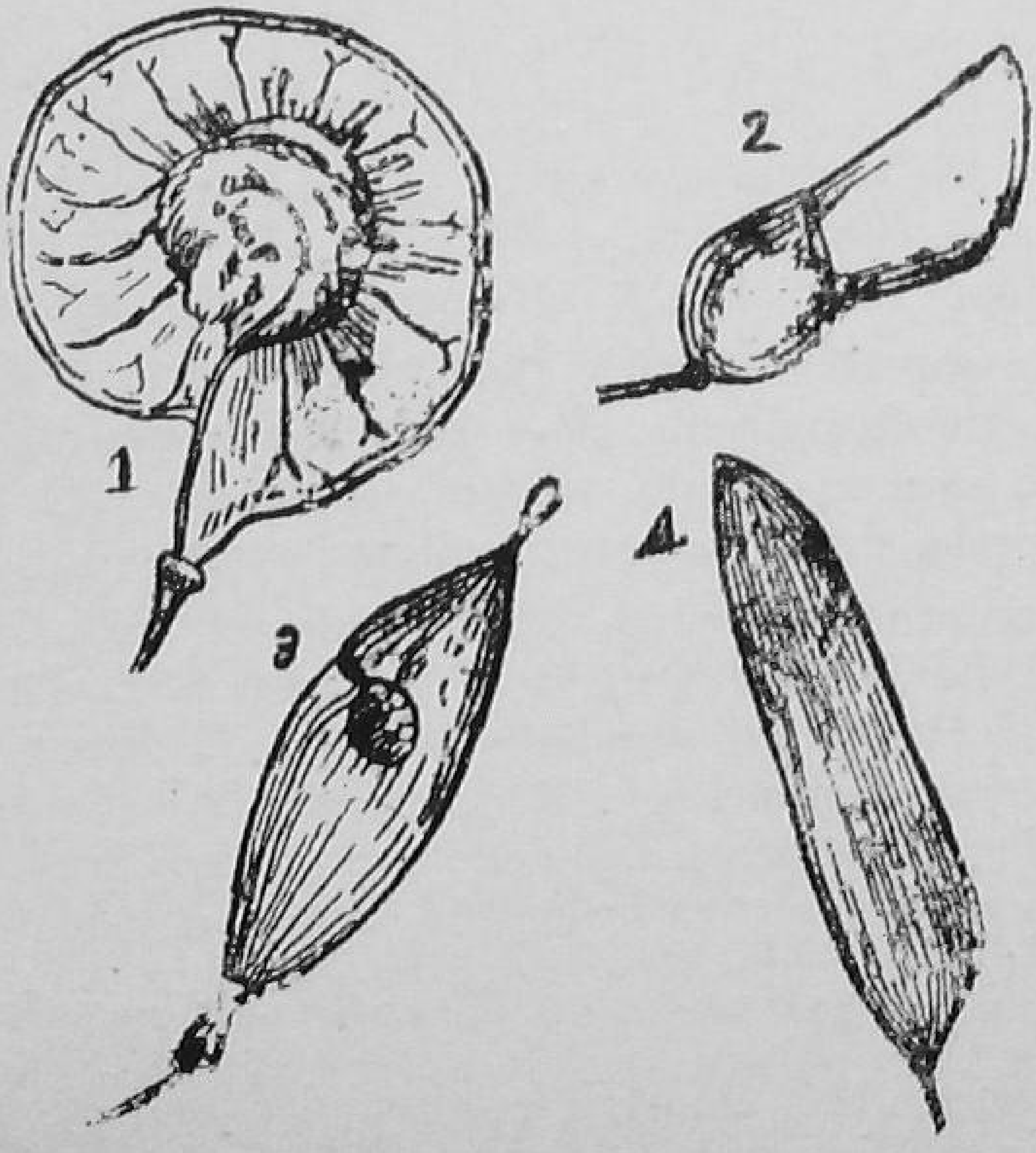


Fig. 140. Winged fruits. (1) *Pterocarpus* (2) *Pterolobium* (3) *Ailanthus*, (4) *Hardwickia*.

absolute necessity, as otherwise the maintenance of the average number both as regards the individuals and the species becomes impossible. Further, these seeds should also get distributed far and wide. Most of the special features that are seen in fruits and seeds are useful in helping the distribution of seeds. If all the seeds that are produced by a plant were to fall beneath the tree or near it and germinate there, a keen struggle is sure to occur and the individuals that may be expected to survive will indeed be few. Even with all the facilities for dispersal a large number of the seeds may fall on barren ground and hence the production of seeds in abundance becomes necessary.

The agents concerned in the distribution of seeds are currents of air, water and animals including man.

(*a*) **Dispersal by wind.**—Fruits and seeds provided with wings or plumes are specially adapted for dispersal by wind because they offer a large amount of surface. The fruits of *Gyrocarpus* (Fig. 141) *Hopea, Holoptelea, Pterocarpus, Pterolobium, Hardwickia, Fraxinus, Ailanthus* and *Combretum* are winged (Fig. 120). In the first two, sepals develop as wings and in the others they are expansions of the pericarp. Amongst seeds that have wings, we may mention those of *Tecoma, Oroxylum* and Cedrela. The fruits and seeds mentioned above are all produced by tall trees. As these fruits and seeds have some weight the height is an advantage; the current of wind is stronger above than below. However, it should not be thought that waftage by wind of fruits and seeds is confined to trees alone. Even low plants have fruits and seeds with adaptations for dispersal. For instance, the achenes of most of the Compositæ are provided with pappus hairs, considering the low position of the herbs, the parachute like pappus hairs of the fruits of *Tridax* and several other plants of the family Compositæ are far more efficient for their dispersal than wings. (Fig. 142). The seeds of many species of the family Asclepiadeæ are provided with tufts of hairs (coma), growing from near the micropyle at the narrow end. Plants of these two families have a very wide distribution, on account of these special adaptation in their fruits and seeds for dispersal.

Fig. 141.
Winged fruit of *Gyrocarpus*.

In many plants the seeds are very minute in size and also very light. This of course renders the seeds most suitable for

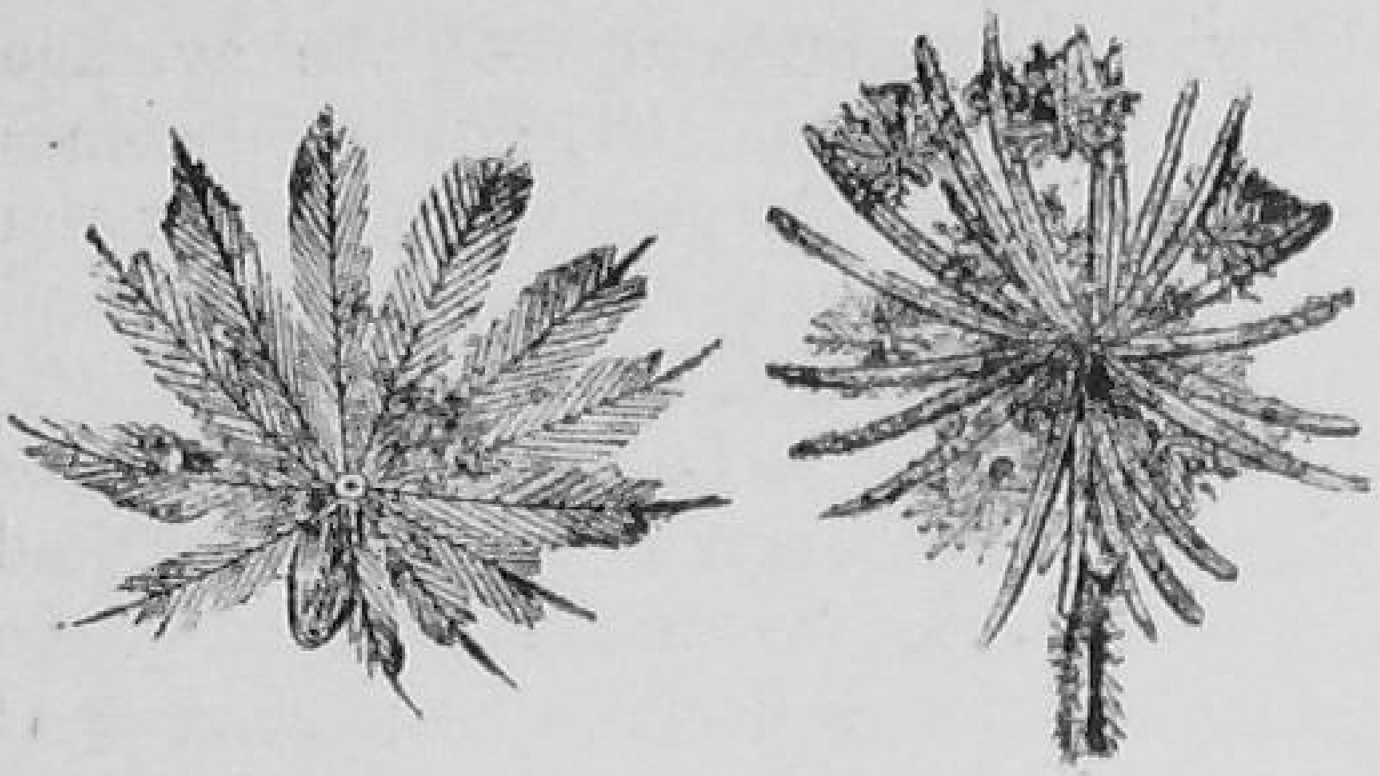


Fig. 142. Achenes of *Tridax*.

dispersal by wind. Many of the epiphytic orchids are able to thrive well in moist tropical forest, because of their seeds being minute and light. Seeds of some orchids have also a loose reticulate testa with plenty of air inside.

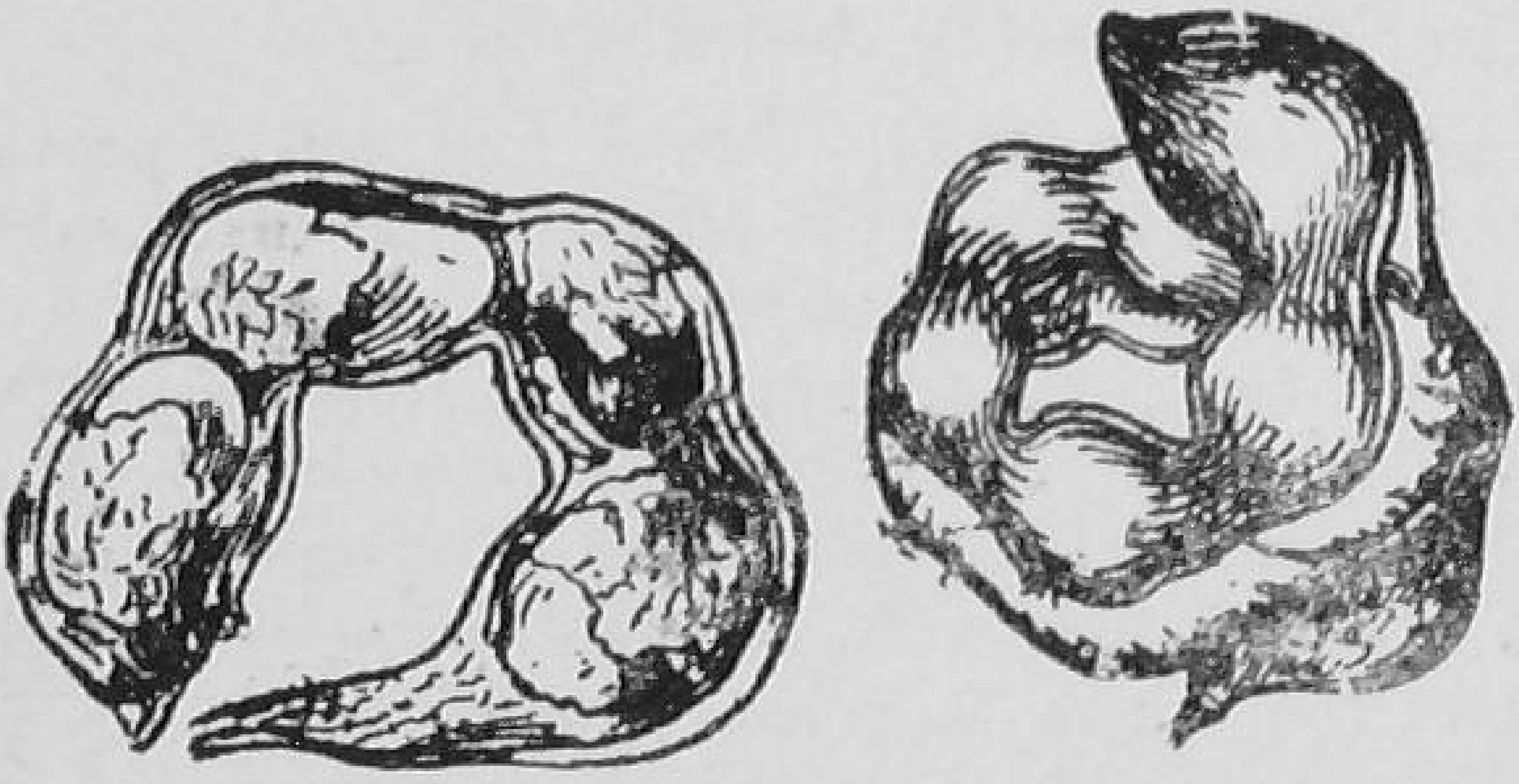
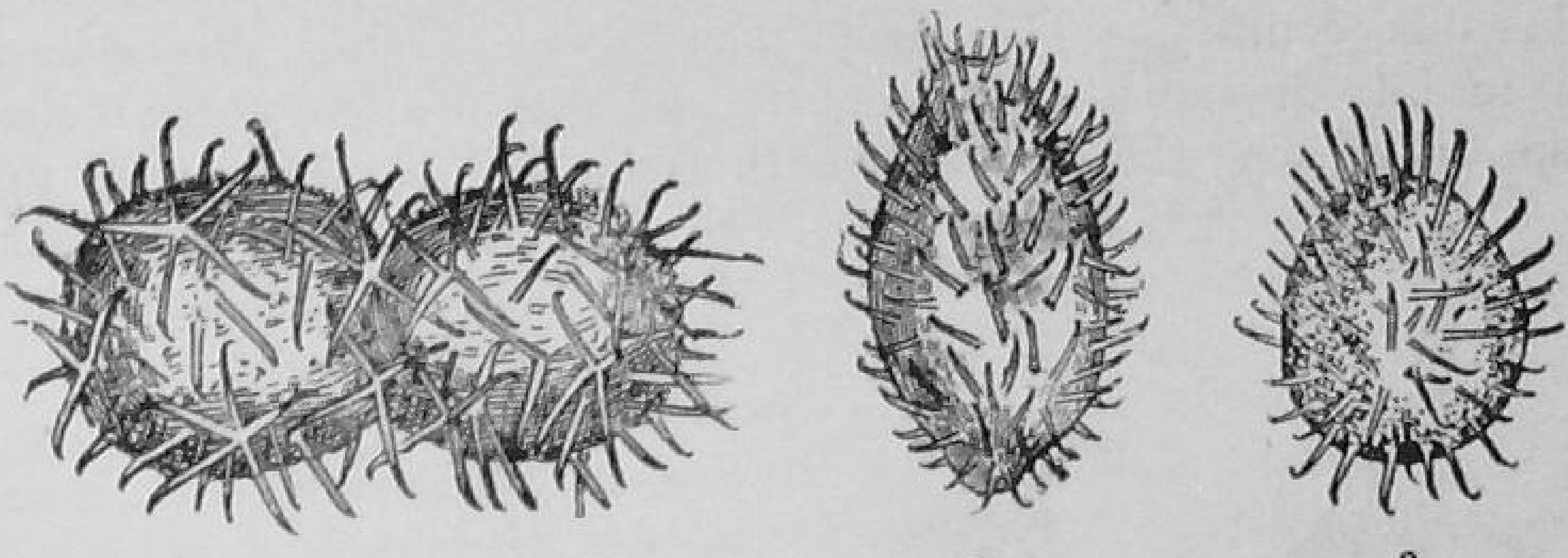


Fig. 143. Fruit and arillate Seed of Pithecolobium.

(b) **Dispersal by animals.**—Animals also serve as agents in the distribution of seeds. Fleshy fruits are meant to bring about the distribution of seeds by means of animals (Fig. 143). Animals deliberately go in search of fleshy fruits for food and devour them. As already pointed out fleshy fruits have either seeds with hard testa or they are covered by hard endocarps, as in drupes and pyrenes. After eating the fleshy part, animals drop the hard seeds in various places. If fruits are swallowed the seeds do not suffer in any way and they are avoided by the animals. In several instances passage of the seeds through the digestive tract of animals assists the seeds in germination. Fruits develop bright colours when they are mature so as to be attractive to animals. In unripe fruits seeds would be in immature condition, and so they do not become differentiated in colour from the foliage leaves. This mode of distribution is very common and it ranks very high among the different modes of dispersal and is second only to dispersion by wind.

Some seeds have arils which cover the seeds and make them attractive. Birds secure these seeds for the sake of eating the edible arils and then they drop the seeds in different places

Hooks, spines and sticky glands are other devices in some fruits to make them cling to the bodies of animals roaming amongst



1 2 3

Fig. 144. Hooked seeds. (1) *Pupalia;* (2) *Xanthium;* (3) *Triumfetta.*

herbs and shrubs (Fig. 144). If we examine our clothing after a walk through a waste place overgrown with weeds, we find many kinds of fruits sticking to our clothing. Fruits of the plants *Pupalia, Desmodium, Achyranthes, Triumfetta, Aristida, Tragus* and *Boerhaavia* are some examples. In *Pupalia* imperfect flowers develop into hooks. The tips of the perianth are the parts that stick on in *Achyranthes* and *Alternanthera echinata* (kaki weed).

In the case of the fruits of *Boerhaavia*, glandular stalks are borne by the persistent portion of the perianth. Hooks develop from bracts in *Xanthium* and *Tragus*.

The drupes of *Martynia diandra* are very innocent looking when succulent (Fig. 145). But very soon the fleshy outer part dries up leaving the hard black endocarp well exposed with two stiff curved hooks at the free end of the fruit. These hooked spines cling on to the body of animals and at this stage the fruit is very easily detached.

(c) **Dispersal by dehiscence.**—Some dry fruits, especially legumes, get dispersed by their bursting, and the valves becoming twisted. Seeds are hurled to some distance in this case. The schizocarps of *Ricinus* also behave similarly. As the pericarp of the fruits dries, they suddenly burst and the seeds are scattered.

(d) **Dispersed by water.**—Water also is helpful in the matter of dispersal of seeds. Fruits such as those of *Cocos nucifera, Cerbera manghas, Lotus* and *Entada scandens* are carried to distant place by waves of water. Ocean currents play a great part in the distribution of fruits and seeds.

(e) **Dispersal by Human Agency.**—The distribution of food and other economic plants is entirely the work of man. So far as these plants are concerned, distribution is brought about by

man deliberately and consciously. He is also responsible for unintentional distribution of several weeds which, though not indigenous to the local flora, have established themselves firmly in this country. The conspicuous weed *Tridax procumbens* is an introduction into this country and within a few years it has spread all over the place in South India and has even gone up to higher altitudes to about 4,000 feet. Other weeds of recent introduction are *Flaveria australasica*, and *Acanthospermum hispidum*. Another weed *Alternanthera echinata* (kaki weed) with prostrate habit of the family Amaranthaceæ is now fast spreading all over south India. This is evidently a very recent introduction, because ten or eleven years ago this plant could not be seen anywhere. The amarantaceous plant *Gomphrena decumbens*, now found as a bad weed everywhere in the city of Madras was not seen twenty years ago. These two introduced weeds are figured under Amarantaceæ. With the present day means of very rapid transport namely airplanes, fast trains and ships, it will not be a wonder if plants (seeds and fruits) are distributed from place to place with a rapidity which was not heard of before.

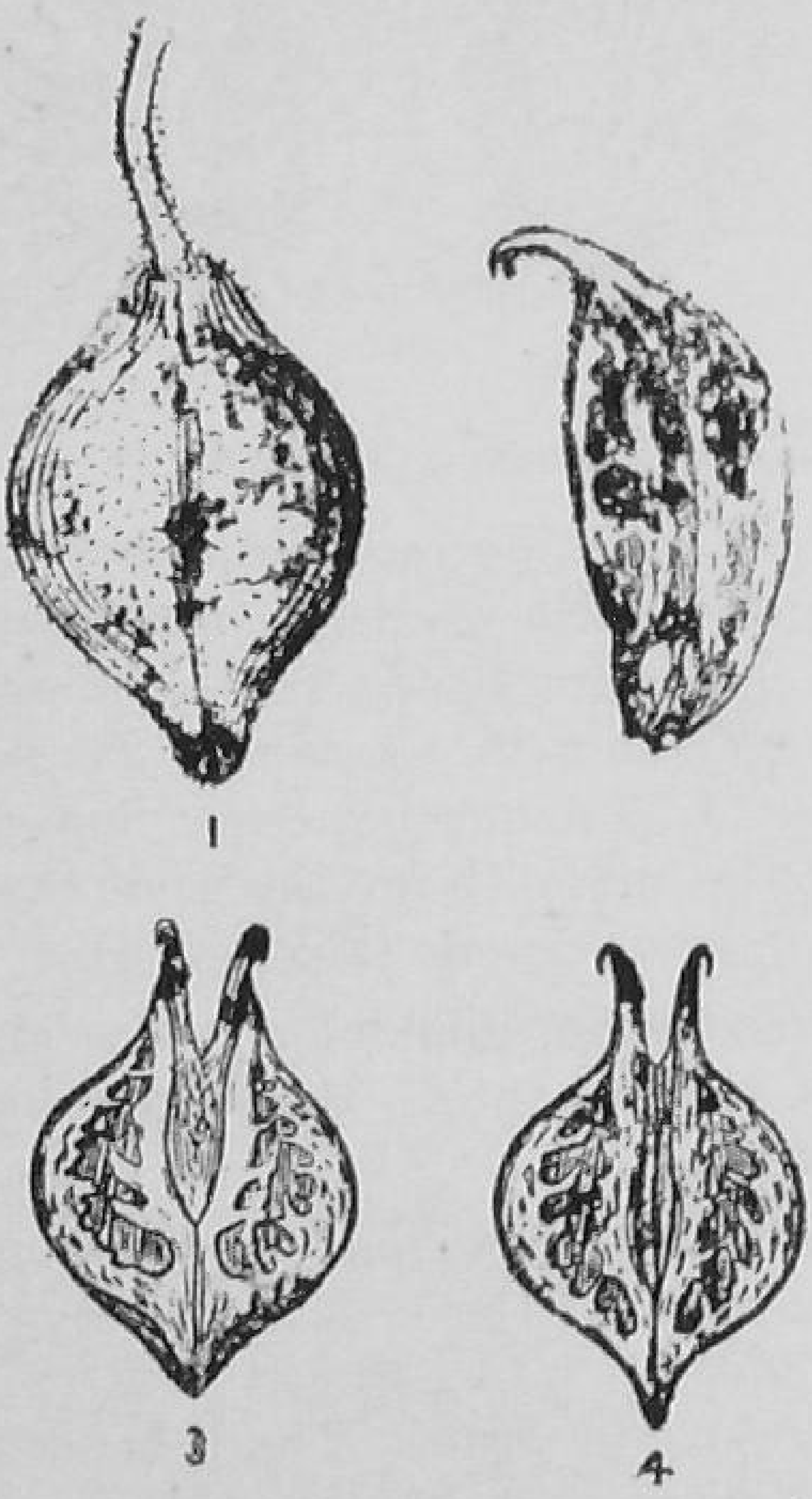


Fig. 145. Fruit of *Martynia diandra*. (1) enfire fruit (2), (3) and (4) with the endocart only and curved stiff hooks.

CHAPTER XI

PLANT CELL

Cell.—Every plant big or small begins its life as a small bit of protoplasm, and it is called a cell. In the case of Spermatophytes we have seen that this cell results from the fusion of two cells from two distinct sources. By repeated division this single cell becomes a mass of cells constituting the embryo. So long as the embryo is dormant and within the seed, it consists of cells more or less homogeneous. Soon after germination, the embryo begins to grow and increase in size. This growth and increase in size are brought about by further formation of cells by division and their transformation; and these two processes go on incessantly in a plant so long as it is alive. Thus we see that the cells are the **structural units** or elementary organs of plants.

When Robert Hooke examined a piece of cork tissue under the microscope in the year 1667, he compared the structural units of cork to " the cells of a honey comb " and used the term cell for the first time to denote the cell wall and the cavity enclosed by it. The protoplasm, the essential part of the cell, was not recognised till about the middle of the last century. Our present knowledge of the structural details of protoplasm is mainly derived from the researches of Schleiden, Robert Brown, Hugo Von E. Mohl, Cohen and Strasburgher. The nucleus was discovered by Robert Brown, and the semi transparent viscous substance found inside the cell was first recognised as the physical basis of life and named **protoplasm** (protos-first, plasma-form) by Von Mohl.

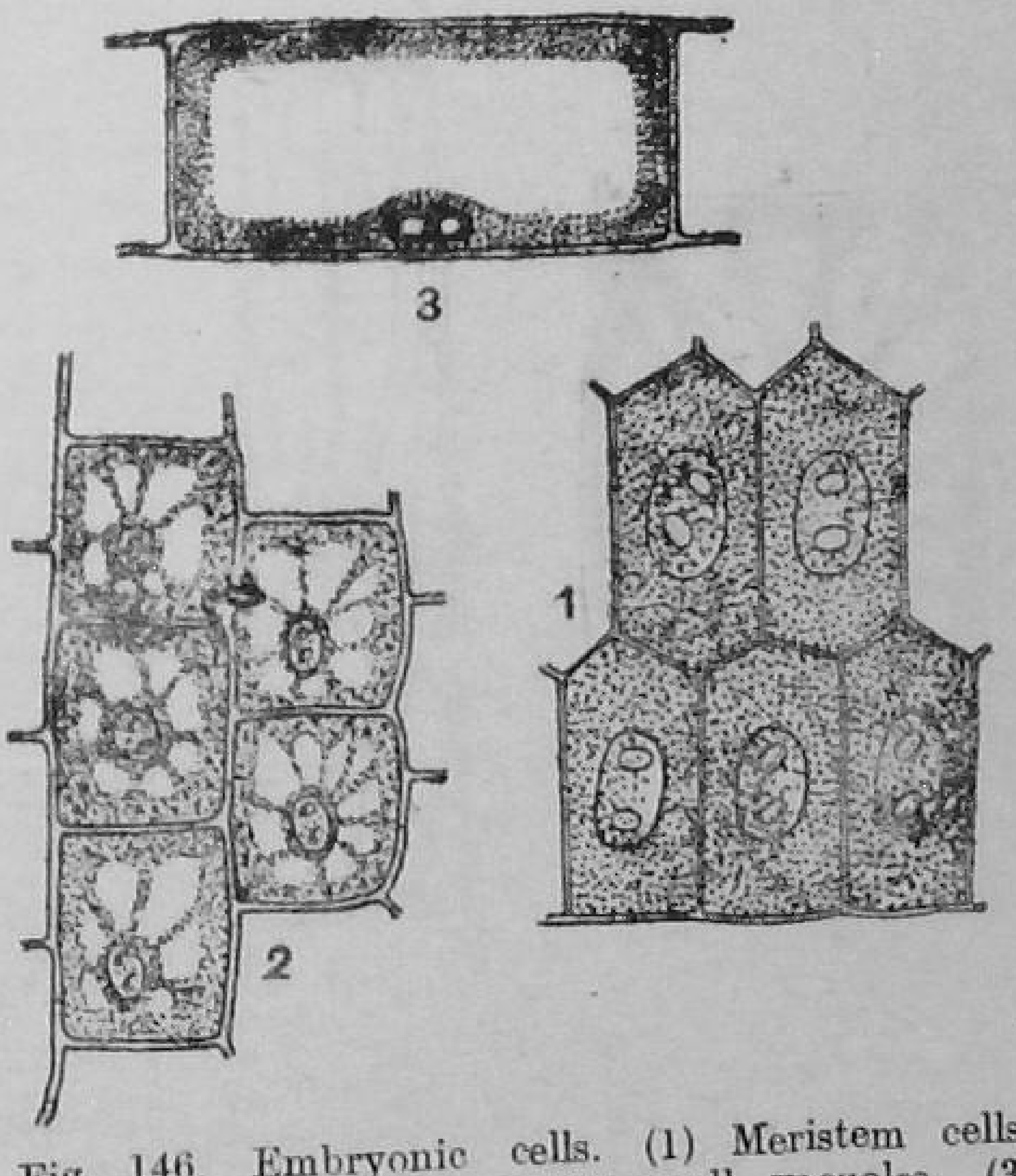


Fig. 146. Embryonic cells. (1) Meristem cells. (2) Young cells with many small vacuoles. (3) an old cell with one large vacuole

By an examination of a thin longitudinal section of the growing point of a root or stem we can learn the constituent parts of a cell. When such a section is examined under the high power of the microscope, it is seen to be made up of a large number of rectangular cells which are separated from one another by very delicate **cell walls.** All the cells are full of protoplasm which is very dense. In every one of these cells lies a large oval or spherical body occupying a fairly large part of the cavity. This is the **nucleus** of the cell. The space between the cell wall and the nucleus is occupied by a finely granular substance and it is termed **cytoplasm.** A number of small refractive bodies without any colour are found imbedded in the cytoplasm, and these are called **plastids** or **chromatophores.** The cytoplasm, nucleus and the plastids constitute the living contents of the cell. (Fig. 146).

A mature cell has also the same parts that are found in the cell at the growing point, but the protoplasm does not occupy the whole of the space. The embryonic cells increase in size by the growth of the cell wall in all directions and the protoplasm also grows and increases in amount up to a certain limit, but does not increase in proportion to the growth of the cell. In the enlarged cells we see cavities of **vacuoles** of different sizes in the cytoplasm, and these contain water in which various substances organic and inorganic are dissolved.

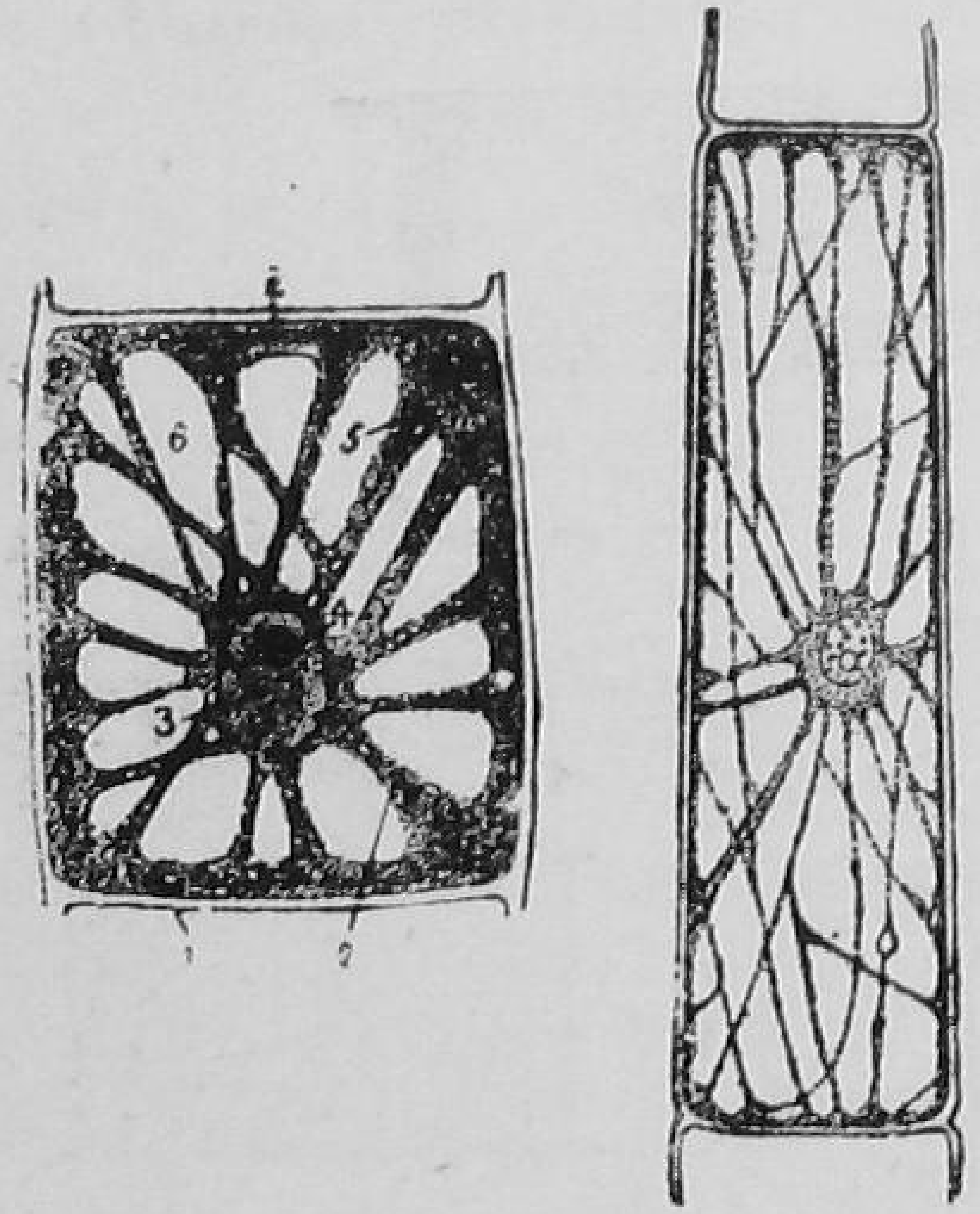


Fig. 147. The typical vegetable cell in a nature condition from the hair of *Cucurbita*. (1) cell wall (2) protoplasmic stand (3) muclens (4) mucleolus (5) chloropast (6) vacuole.

To have an idea of a mature cell showing the protoplasm in a living state, the hairs growing on the sepals of the flower buds of *Cucurbita maxima* may be examined under the microscope. (Fig. 147). A hair consists of a number of cells and the cell walls are transparent. By confining our attention to a single cell of the hair we can make out all the parts clearly and learn a great deal about the behaviour of protoplasm in a living cell. The cell is bounded externally by a distinct cell wall of uniform thickness. The walls separating

the cell under observation from the cells above and below sometimes show shallow pits. Each protoplast is thus completely enclosed by an elastic membrane or **cell wall** which consists mostly of cellulose. A thin layer of cytoplasm is in contact with the cell wall at all points and encloses a large internal cavity of **vacuole** which is filled with a watery cell sap. The nucleus which is highly refringent lies suspended in the centre of the cell by means of a large number of threads and strands of cytoplasm running from it to the film of cytoplasm lining the cell wall. The nucleus is always surrounded by a sheath of protoplasm. In other words, whatever position the nucleus may occupy in the cell we find it always embedded in the cytoplasm. The cytoplasmic threads traversing the cell cavity may show branching. Crystals and plastids are often found imbedded in the cytoplasmic strands and in the layer lining the cell wall. In a fully mature cell we find only the cytoplasmic layer lining the cell wall with a large single vacuole filled with cell sap. The nucleus in this case occupies a parietal position in the peripheral cytoplasmic layer.

Living Contents

(i) **Protoplasm** in the living cell is viscous, semiliquid and jelly like. It behaves as a liquid. Although enclosed in a cell wall the cytoplasm frequently shows movements, as may be seen in the cells of the hairs of *Cucurbita*. Both the layer lining the cell wall and the strands traversing the cavity show the streaming movement. Within the same cell the movement will be in one direction in some strands and in others in the opposite direction. Occasionally in the same strand streaming movement in opposite directions may occur. This streaming movement is called **Circulation.** The staminal hairs of *Cyanotis* also show circulation very well. (Fig. 148). The protoplasts in the cells of some plants, especially in those of aquatic plants, show movements of a different kind, called **Rotation.** Rotation occurs only in cells in which the cytoplasm is reduced to a layer lining the wall and enclosing a large continuous vacuole. The cells of the leaves of *Vallisneria* and *Chara* are particularly good for the study of rotation in protoplasm. (Fig. 149). The movement is only in one direction and it follows the cell wall. In a cell the direction of the movement may be left to right and in the cell next to it, it may be in the reverse direction.

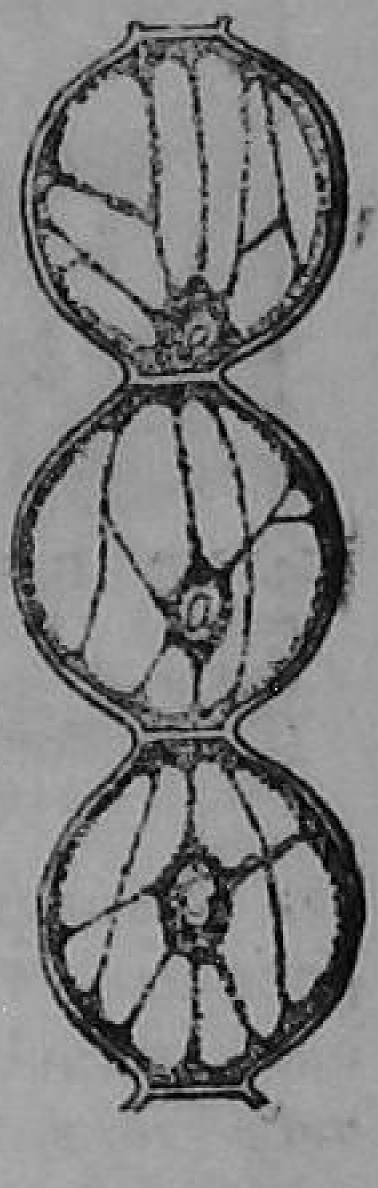


Fig. 148. Cells of the staminal hair of *Cyanotis*.

Protoplasm is capable of perceiving different kinds of stimuli and responding to them in a suitable manner. This power of the protoplasm is called irritability. All the processes connected with the nutrition of the plant and reproduction are initiated and carried out by protoplasm. In short, the specific nature of the entire plant is dependent on the control exercised by the protoplasm.

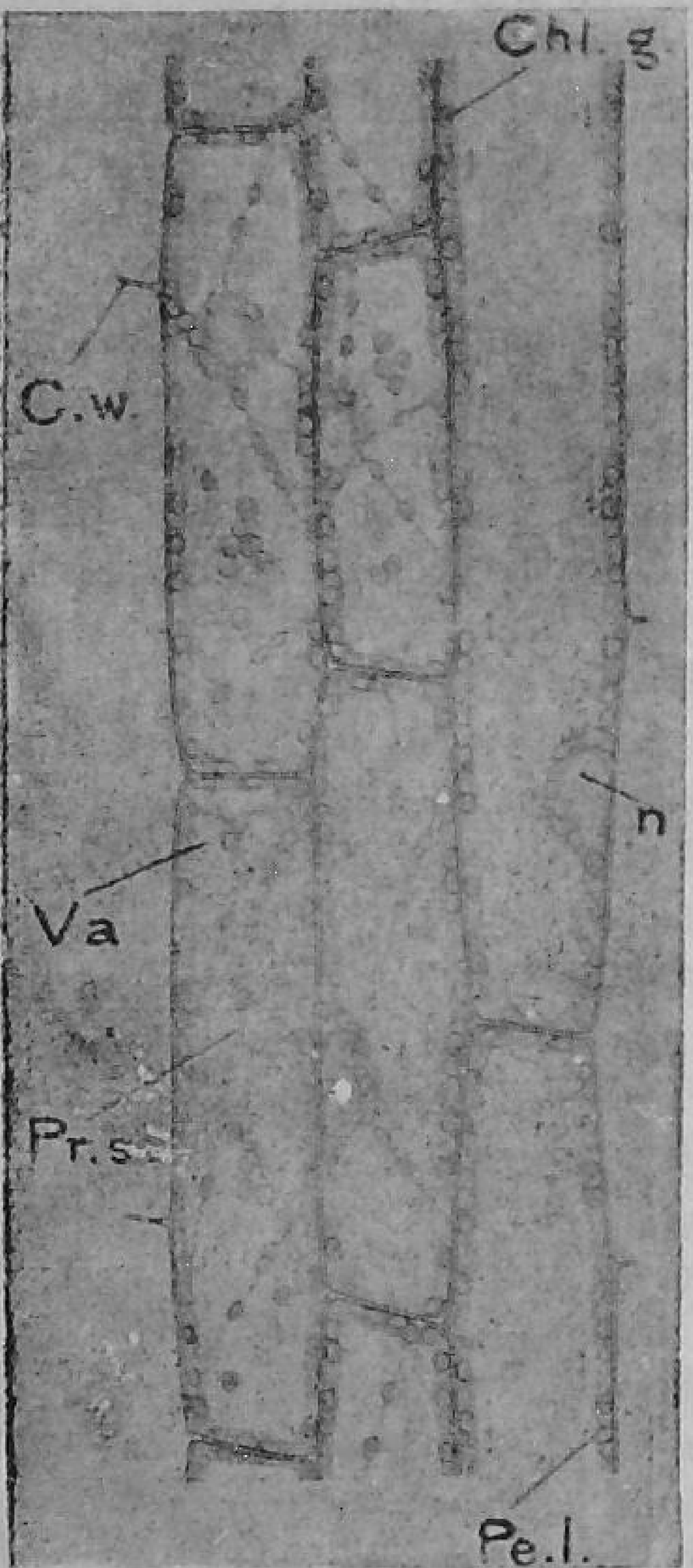


Fig. 149. Cells of the leaf of *Vallisneria spiralis*. (Chl. g) Chloroplast. (C. w) Cell wall. (n) Nucleus (Va) Vacuole (Pr. s) Protoplasmic strand. (Pe. l) Peripheral layer of protoplasm.

A very large portion of protoplasm in the living condition is water. Protoplasm consists of highly complicated unstable substances which are subject to continual changes. Proteins form the largest part of it. When in the living condition protoplasm is alkaline or neutral in reaction, but never acid. In the living protoplasm a large number of proteins and several other organic substances occur. This substance is actually alive only within a narrow range of temperature. At temperatures above 50 C it becomes coagulated. Acids and alcohol also cause it to coagulate.

(ii) **Cytoplasm.**—In general appearance cytoplasm is alveolar. When highly magnified we can distinguish in it a clear hyaline external layer. This peripheral boundary layer called **Primordial Utricle** and the inner granular layer bounding the vacuole called **Tonoplasm** are very important parts of the protoplast, as the passage of substances is determined by them. Further, this clear plasmatic layer is renewed whenever it is injured. Cytoplasm is really made up of a large number of very minute granules and droplets not visible under the ordinary microscope, but visible when examined with the ultra microscope. Since protoplasm consists of minute ultra microscopic particles it is considered to be

a colloidal solution. This conception of the protoplasm helps to explain many a vital process on a physico-chemical basis.

Since protoplasm is enclosed by the cell wall it may be thought that a cell is isolated and not connected with the other cells around it. But there is sufficient evidence to conclude that all the cells of living tissues are in intimate relation to one another. It is now established beyond doubt that in the mature tissues of at least some plants there is continuity of protoplasm from cell to cell. (Fig. 150). Extremely fine filaments of protoplasm pass from the boundary layer of the protoplasm of a cell to the similar layers of protoplasm in the surrounding cells either through the entire thickness of the cell wall or through the pit membrane. On account of these connecting filaments of protoplasm the whole of the plant body becomes an organic unit. This connection of protoplasm with that of its neighbouring cells by means of fine filaments can be seen in thin section of the endosperm of date seed, if treated with sulphuric acid and chlorozinc iodine, or methylene blue.

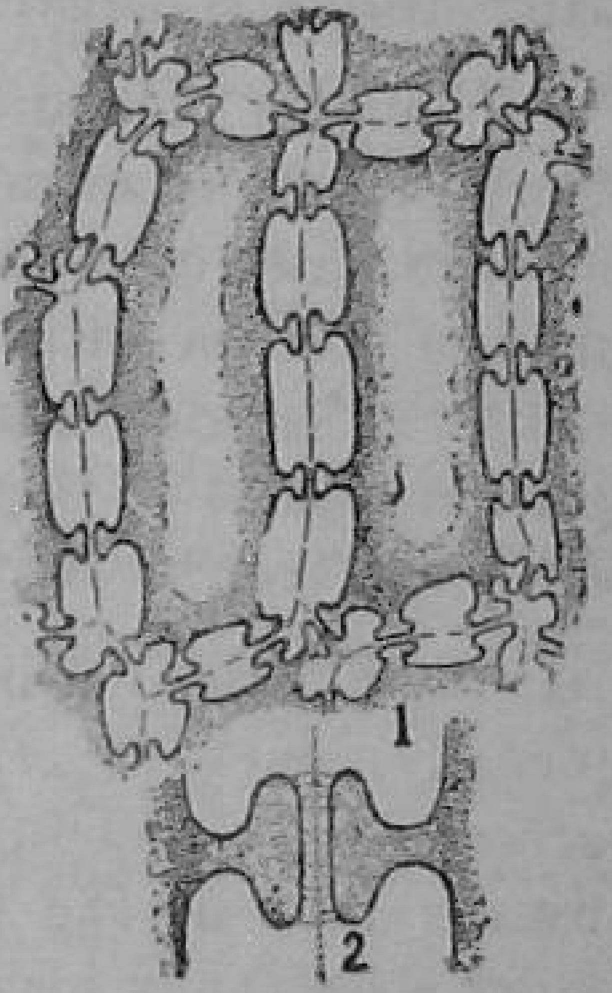


Fig. 150. **Cells in the** endosperm of date seed. (1) cells with pit. (2) a pit highly magnified to show the fine filaments of protoplasm.

(iii) **The Nucleus.**—It is now an established fact that for the maintenance of the protoplast in a living condition nucleus is very necessary. As it performs certain special functions, it should be considered as an organ of the protoplast. In the cells at the growing points the nuclei may be about half the diameter of the cell and it is spherical. In older cells they are oval or lenticular. With the increase of the cell in its volume the nucleus does not increase in size. To make out the structural details of the nucleus, protoplasm must be killed and stained with special reagents.

In the living cell the nucleus has a finely dotted appearance, but when stained, it is seen to consist of a net work of **chrcmatin** or a substance taking a deep stain and consisting mainly of proteins containing phosphorus. In the living condition the nucleus appears to be a kind of fluid like the cytoplasm and surrounded by a nuclear membrane by which the cytoplasm is separated from the nuclear cavity. Within the nucleus a small compact body is found and it is called the **nucleolus** ; sometimes two nucleoli may be seen

The interstices of the net work are filled with nuclear sap. In the nucleus the most important part is the reticulum consisting of threads that do not get stained deeply. But some granular substance imbedded in these threads becomes stained deeply. The threads are called **linin threads** and the granular substance that stains deeply is called chromatin.

The part played by the nucleus in the growth and nutrition of cells is not inconsiderable. If protoplasm is injured, it is only the part which contains the nucleus that is able to repair the injury, and the portion without it is incapable of this process and consequently it is decomposed. It is the nucleus that initiates cell division and it is this body that bears the hereditary characters which are transmitted to other individuals.

(iv) **Plastids.**—These bodies are very small and so they cannot be easily seen in young embryonic cells. But as cells mature they become larger and increase in number by division. In the cells forming part of the vegetative region, such as leaves and young tender stems they become green and then they are called **chlorophyll corpuscles** or **chloroplasts.** The green colour of the leaves is due to the presence of chloroplasts in them in myriads. In all higher plants these bodies are ellipsoidal or somewhat spherical, although they assume various shapes in Algae. The framework of the chloroplast is a colourless matrix of specialised protoplasm. The green colour is due to the presence of four pigments, two green, one red and the other yellow. The green pigments are called **chlorophyll a** and **b,** the red **carotin** and the yellow **xanthophyll.** The chloroplasts in young fruits are at first green and, as the fruits mature, they become red and orange and then these bodies are called **chromoplasts.** In petals of flowers colourless plastids change into chromoplasts. In tubers and other parts of plants inaccessible to light the plastids remain colourless and develop into bodies called **leucoplasts.** They are useful in changing sugar into starch and *vice versa*. On exposure to light leucoplasts change into chloroplasts. Plastids being specialised parts of protoplasm, they are derived only from pre-existing bodies and cannot arise *de novo*.

(v) **The Cell wall.—The formation and growth of the cell wall.**—The cell wall is derived from the protoplasm. Naked protoplasm very soon forms this membrane at its periphery. In embryonic cells, the cell walls are very thin and difficult to see. As the cell grows in length and in breadth the cell wall must necessarily increase in length and breadth. Until the cells attain their usual size the cell wall grows only in surface and so it remains thin.

The increase in the surface in the cell wall is brought about by the introduction of new particles between those already existing. This kind of growth is called growth by **intussusception.** The cell walls of cells in certain parts of plants are thick and this thickness is due to the laying down of new layers one above the other by the activity of protoplasm. This process of thickening known as growth by **apposition** goes on, on both sides of the partition wall of two adjoining cells and the newly formed layers are not so refractive as the original cell wall. So the original cell wall stands out clearly in the middle with the new layers on both the sides. This layer being in the middle, it is spoken of as the **middle lamella.** The cell walls of cells found in the hard portions of the plant such as wood etc. show the thickening as well as the middle lamella very well. When the thickening is very great as in fibre cells striations are clearly visible in the cell wall on both sides of the middle lamella. The thickening of the cell wall is never uniform. While some portions are thickened, other portions are not. The variations in the thickening of cell wall is dealt with in another connection.

Chemical composition of the cell wall.—The cell wall consists of cellulose when it is being formed. It becomes mixed with other substances as the cell wall gets older. Pure **cellulose** cell wall is transparent, elastic, soft and permeable to water. Cellulose is a carbhoydrate and chemically considered, it consists of the elements carbon, hydrogen and oxygen. The chemical formula is $(C_6 H_{10} O_5)n$.

The pure cellulose of the cell wall is variously transformed as shown below :—

(i) The original cell wall of cellulose is changed into **lignin** by deposition. It is largely found in the woody tissue. As soon as lignification begins the cell contents or the protoplasm begins to disappear. Parts that have changed into wood can be made out by using the reagents acid phloroglucin and aniline sulphate. The former stains the wood violet red and the latter yellow. Lignin is less permeable than cellulose.

(ii) **Cutin** is deposited upon the original cellulose of the cell wall. This is a waxy substance and as such it is not permeable to water. So this reduces the passage of water from the surface of the plant. Only the epidermal tissue is changed into cutin externally.

(iii) The cell walls of the cells below the epidermis become changed into **suberin.** When thus suberised the cell wall is impervious to water and like cutin it prevents the evaporation of water.

(iv) The cell wall of cellulose in some cases changes into **mucilage** a kind of soft substance when it is wetted with water.

If it is dry, it is hard and horny. Several seeds have coats in them which change into mucilage when they are wetted.

Non-living substance found in the cell

(i) **Cell sap.**—All vital activities characterising plants are initiated in the cell, and therefore we may legitimately expect many substances to be found in the protoplasm. In the vacuoles of protoplasm there is always water in which many substances may exist in solution. Insoluble substances also may exist in the protoplasm.

The cell sap is acid in reaction. The various colours such as red, pink, blue and violet in the petals are due to substances dissolved in the cell sap. Many kinds of salts and sugars may also be in the cell sap.

The insoluble substances may be in the form of very minute particles or drops and these appear as granules, or as refractive bodies. Some of the substances may accumulate in fairly large masses and possess certain definite characteristics, by which we recognise them. Such large bodies usually found within the cells of plants are aleurone grains, crystals, starch grains, and fat or oil.

(ii) **Crystals.**—Crystals of calcium oxalate are found in the cells of many plants. In the cells in which these crystals are found the protoplasm disappears, and the cell serves as a storehouse for the crystal. The crystal may be a simple crystal having a cubic rhomboidal or prismatic form, or it may be a compound crystal consisting of several simple crystals. In some plants these crystals exist as needle shaped ones aggregated in bundles. These kinds of crystals are called **raphides.** (Fig. 151). In some plants, especially in those of the family, Urticaceae, calcium carbonate occurs as a pear shaped body projecting into the cell cavity. This is termed a **cystolith** (Fig. 152). At first a small protuberance of cellulose arises on the cell wall internally, and it gets impregnated with calcium carbonate as it grows larger.

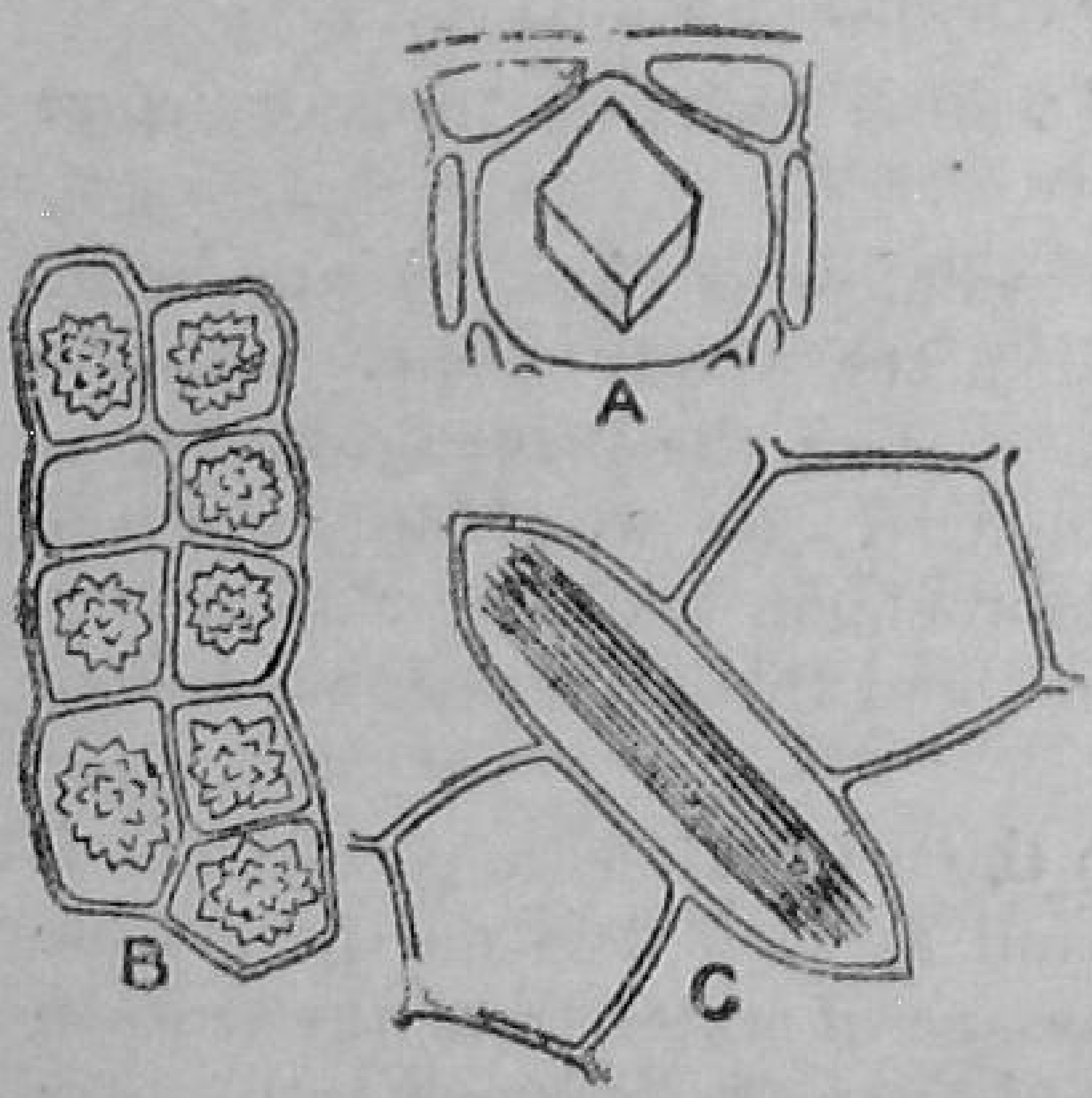


Fig. 151. Crystals occuring in cells. (*a*) Simple crystal. (*b*) Compound crystals. (*c*) Raphides.

(iii) **Aleurone Grains.**—These are protein grains occurring usually in the cells of endosperm or cotyledons of oily seeds. In the endosperm of *Ricinus* seeds these grains are well developed and lie embedded in the cytoplasm. An aleurone grain of *Ricinus* is ellipsoidal in form and it encloses a crystal of albumen and a globoid of double phosphate of calcium and magnesium. These grains also occur, without any inclusions, as small bodies in the cotyledons of many seeds. They are particularly abundant in the peripheral layers of grains of cereal plants. Aleurone grains are abundant in the seeds of Amygdalus, *Helianthus*, and other oil containing seeds. (Fig. 153).

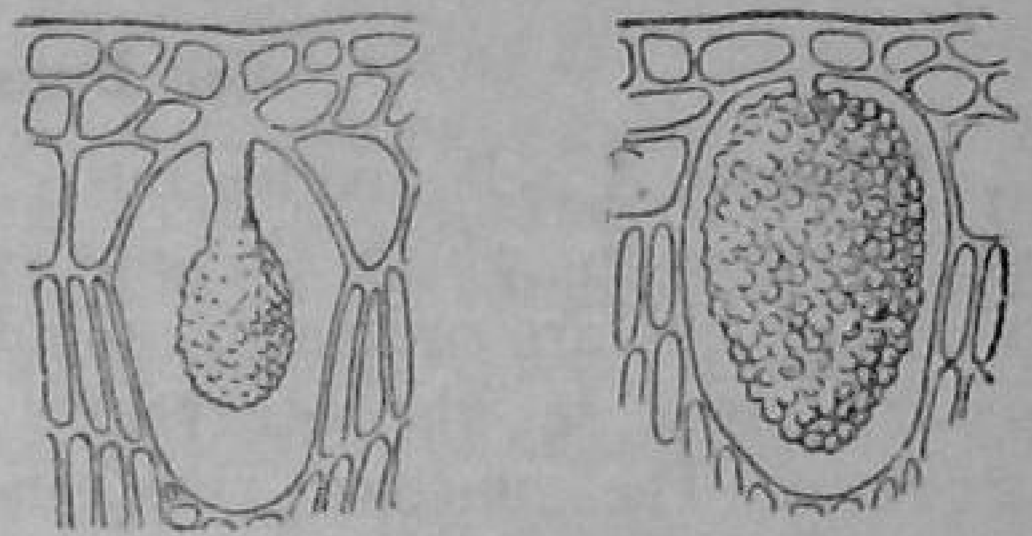


Fig. 152. Crystals of calcium carbonate (cystolith) occuring in the epidermal cells of the leaf of *Ficus*.

(iv) **Starch Grains.**—Most of the living cells in the stem and roots of plants abound in starch grains. In tubers, rhizomes, and seeds starch grains are abundant and they are large in size. They vary very much and most of them show striations. All the starch is really formed within the chloroplast imbedded in the cytoplasm, and the starch grains thus formed are very minute. All the starch thus formed is transported to other parts, in a soluble state, and there again they are deposited as large grains. Leucoplasts are the agents in building up these large starch grains.

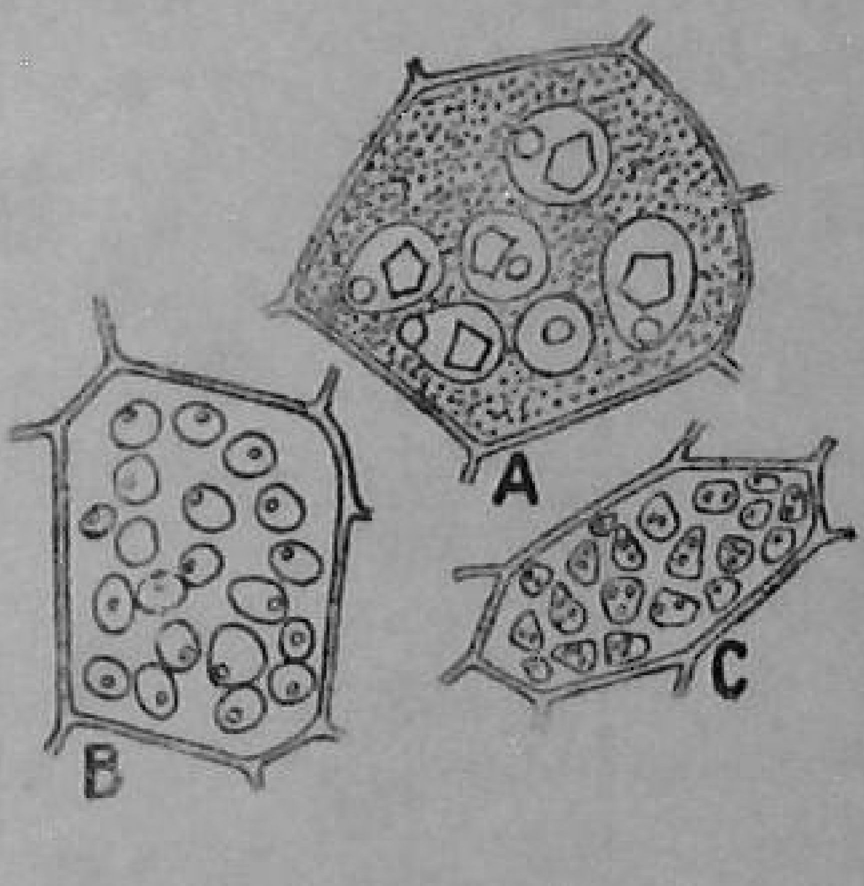


Fig. 153. Aleurone grains of (a) *Ricinus*. (b) *Canthomus* and (c) *Sesamum*.

(v) **Secretory Products.**—For carrying out particular functions protoplasm may secrete special products. When a cell divides, the protoplasm first secretes a **cellulose** wall all around it. Germinating seeds as well as various parts of plants secrete **Enzymes** for rendering stored food material soluble and for carrying on other vital processes such as respiration.

(vi) **Waste Products.**—In the course of the metabolism of the plant certain products may not be required for vital processes.

These products are deposited in certain parts of plants such as bark, dead wood, etc. They are generally tannins, gums, resins, essential oils and minerals.

Cell Division

Mitosis.--A cell divides into two daughter cells by a complex process in which the nucleus plays an important part. Dividing cells are ordinarily much smaller than those of the mature tissues to which they give rise and are very uniform in structure. The nucleus, here relatively large in proportion to the rest of the cell, is the structure which takes the most active part in division, for before the entire cell divides into two, the nucleus itself does so by a characteristic process known as **mitosis** or **karyo-kinesis** or **indirect division** (Fig. 154). This cannot well be

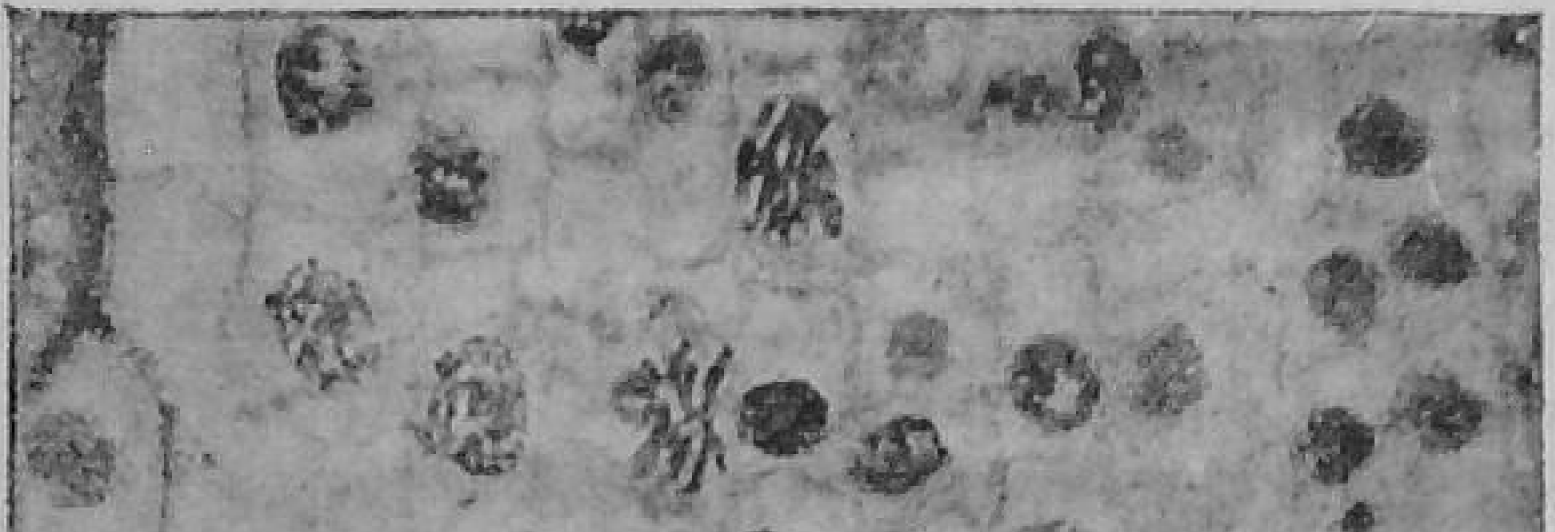


Fig. 154. Cells in a longitudinal section of a root of *Tradescantia* showing division of the nucleus and the chromosomes.

Note the Anaphase stage of the division in the third row and the metaphase stage in the other rows of the cells.

studied in living tissue and a knowledge of it has been derived from microscopic examination of fine preparations which have been carefully stained.

Within the nucleus of a cell which is not undergoing division and which in respect to this process is said to be in "**resting stage**" there is a net work often very fine and hard to distinguish as such, consisting chiefly of a substance which stains very deeply with certain dyes used in the study of cell structures and this has received the name of chromatin. When a cell is preparing to divide, the rod shaped or elongate bodies known as **chromosomes** appear distinctly in the nucleus. The chromosome threads appear longitudinally split into two, but the split halves or **chromatids** are held together at a constriction known as **centromere.** This stage in nucleus division is known as **prophase.** For any given species the number of chromosomes in a cell is characteristic and constant. Thus, in the somatic cells of rice plant, there are always 24, in those of cholam 20, or 40, in tobacco 48, and in onion 16. Further more, each chromosome is a differentiated chromatin thread, has its own persistent individuality in size and shape which is repeated at every cell division and which can be recognised by the skilled worker in the line. In the second stage of cell division, two poles or apparent centres of attraction, arise in the cytoplasm on opposite sides of the nucleus and from each of these poles a mass of delicate fibres go inward to the nucleus. The nuclear membrane now disappears, and the fibres extend into the nucleus and some of them are apparently attached to the chromosomes at centromere and others extend continuously from one pole to the other. The entire fibre-like structure extending between the poles is known as **spindle.** The chromosome pairs now move into a plane or **equatorial plate** stretching across the cell at right angles to the spindle and this stage marks the **metaphase** of the division. Each chromosome has a spindle fibre attached to it and for the sister chromatids the two halves of each of the original chromosome the fibres run to opposite poles. At late metaphase, the centromere splits into two and the sister chromatids repel each other and the split halves move apart. One set of chromatids move towards one pole and the corresponding halves of these forming the second set move towards the opposite pole. This stage is named the **anaphase.** Each chromosome group now consists of the split halves of the 2n chromosome of the somatic cell and in the process of the division there has been no change either in the total number or quality of chromosomes that enter the daughter cells. At the two poles, the chromosomes undergo a reversal of the changes that take place in prophase and this stage is termed **telophase.** Nuclear membrane is formed. Meanwhile a new cell wall is being laid down between these two nuclei usually through the minute thickenings at the middle points of the fibres which still connect the nuclei, and the

union of these thickenings into a continuous **cell plate** which ultimately extends across the cell. Telophase is followed by the

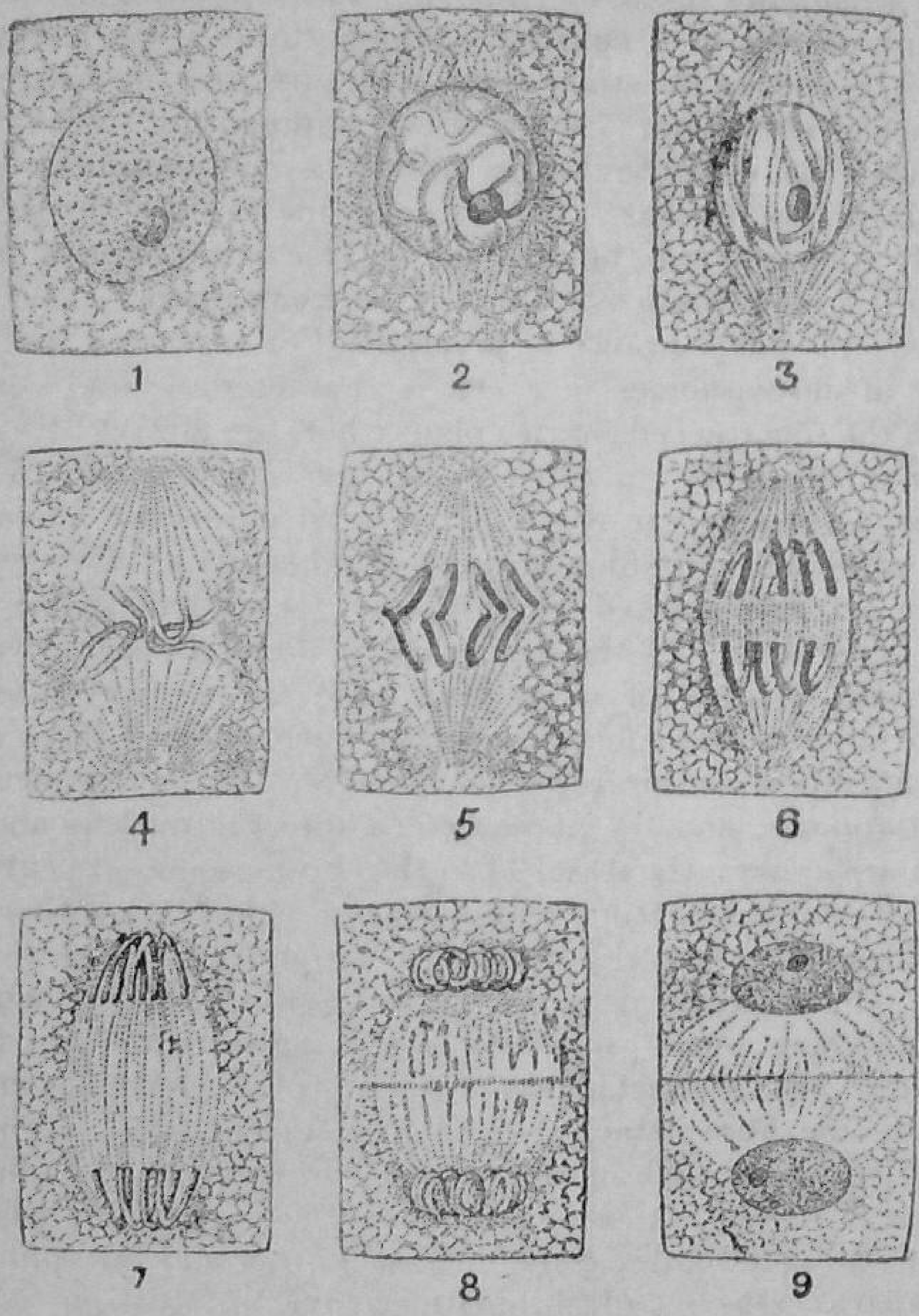


Fig. 155. Diagram of indirect nuclear division or mitosis. (1-3) prophase. (4) metaphase. (5-7) anaphase. (8-9) telophase.

splitting of a new cell wall, which completes the division of the mother cell into two similar daughter cells. This complicated process of cell division is concerned with the accomplishment of an exactly equal division of the chromatin material between the two daughter cells and thus among all the cells of the plant body, suggesting the conclusion that the chromatin is of the utmost importance in directing the growth and differentiation of the organism. As division progresses, the original cell increases somewhat in size,

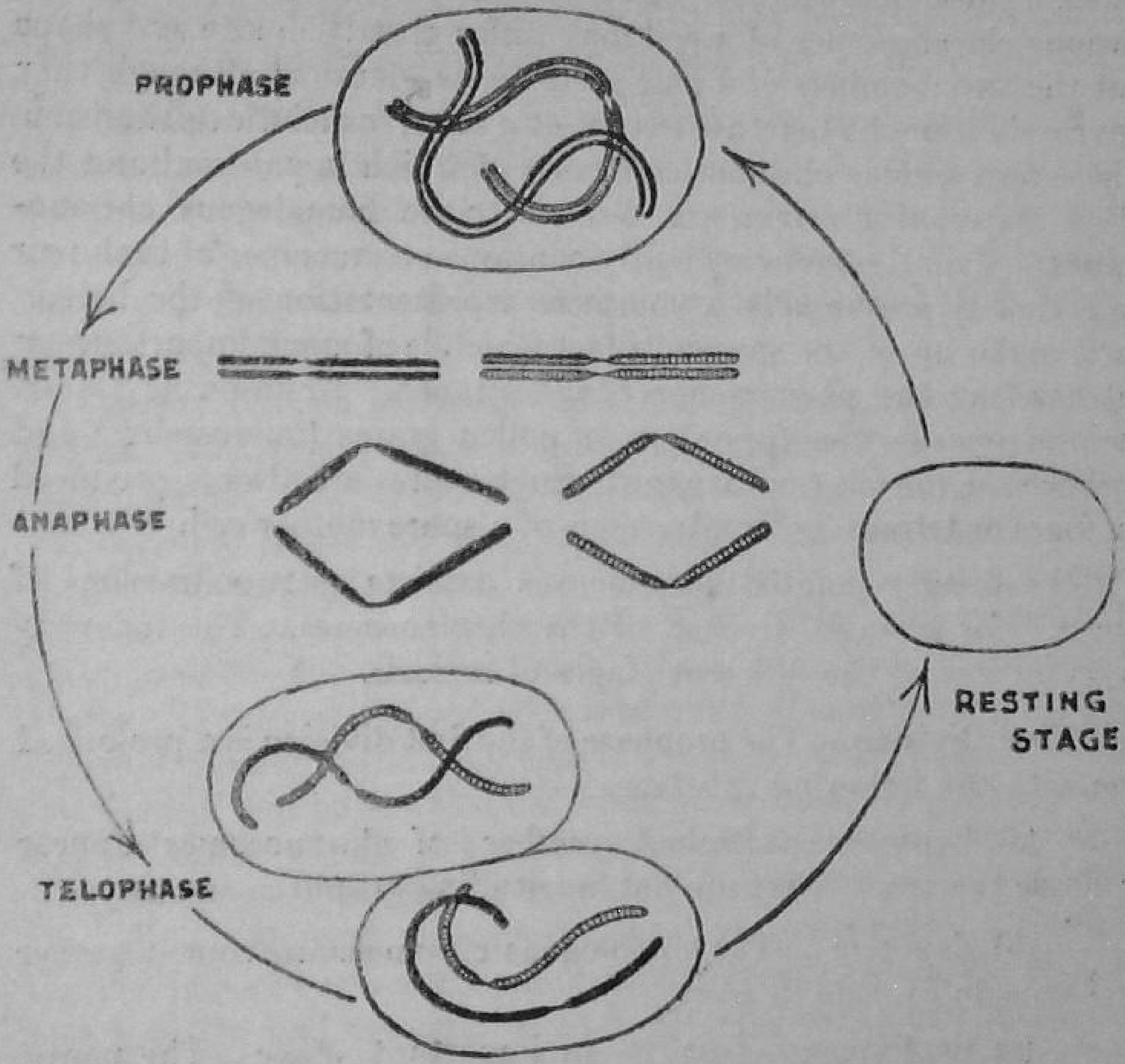


Fig. 156. Diagrammatic representation of the different stages in mitosis.

so that by the time the two daughter cells are formed or shortly thereafter, each is as large as the original mother cell. This increase is due to an increase in the living material of the cell, and it is here that new protoplasm is being produced most rapidly from its various constituents. Regions of cell division—root tip, shoot tip,etc., are those of active synthesis of protoplasm.

Reduction Division or Meiosis.—For a proper understanding of inheritance and of plant life cycles, one must carefully study cell division preceding the formation of both male and female gametes. Here, the chromosomes do not split and then separate as in mitosis. On the other hand, for a single division of the chromosome there are two divisions of the cell and as a consequence each daughter cell or **gamete** possesses half the number of chromosomes found in somatic cells. Such a **reduction division** is termed **meiosis**. A male and a female gamete, each with a **haploid** (n) complement of chromosome, unite at fertilisation, and the double or **diploid** number, characteristic of the species is restored and

persists throughout in the vegetative parts of the new plant. The various chromosomes of a cell may differ greatly in size and shape but the two members of a pair seem to be identical although they are rarely brought together except at a stage in meiotic cell division. These two similar chromosomes, one of which is paternal and the other maternal in origin, are termed to be **homologous chromosomes.** Every gamete evidently contains one member of each pair and this is presumably a complete representation of the hereditary make up of the species, a fact which is of much importance in interpreting the phenomenon of inheritance. In flowering plants, meiosis precedes the formation of pollen grains (microspores) and embryo-sac initials (megaspores). Such spores are always produced in fours or **tetrads** by two divisions of a spore mother cell.

As already pointed out, meiosis consists of two divisions of the cell for a single division of the chromosomes. The following is an outline of the different stages of meiosis.

First Division.—The prophase of the first division is a prolonged one with the following substages:—

(*a*) Leptotene.—Diploid number of chromosomes appear in single threads. They are not longitudinally split as in mitosis.

(*b*) Zygotene.—The homologous chromosomes come together and lie side by side in pairs.

(*c*) Pachytene.—This is an important stage. The paired chromosomes coil round each other. The chromosomes are longitudinally split. At the fourstrand stage there is exchange of segments between the homologues.

(*d*) Diplotene.—The chromosomes begin to fall apart, the sister chromatids being held together at centromere. At the points where there had been exchange of segments cross-shaped exchanges termed **chiasmata** are evident. The chromosome threads spiralise and hence become shorter but stouter.

(*e*) Diakinesis.—Nucleoli may disappear at this stage and the condensation of chromosomes continues.

Metaphase I.—The chromosomes lie distributed at the equational plate. The sister chromatids, which have now changed in their structure by exchange of segments with their homologues are held together by centromere. The latter does not divide now (cf. mitosis).

Anaphase I.—The centromeres of the homologous pair of chromosomes begin to move to opposite poles. This results in the separation of the homologous pair to opposite poles. This

reduces the number of chromosomes at each pole from 2n to n.

Telophase I.—At the two poles formed at first division, the two daughter nuclei are reconstituted and they go to resting stage.

Second Division. With very short or no resting stage, second division starts. This is similar to mitosis. The centromere divides at the second metaphase and at anaphase II the sister chromatids pass to opposite poles. At telophase II, four daughter cells by two successive cell divisions are formed, each with haploid number of chromosomes in the nucleus.

At fertilisation the male and female gametes fuse to form the zygote. The zygote then contains 2n chromosomes, one n from each gamete. The zygote, in the higher plants undergoes mitotic cell division, forms the embryo and grows into an adult . When the flowering plants reach the reproductive phase, they again form the gametes in the flowers. The body cells contain 2n chromosomes—the number with which the zygote started to divide. If the gametes were to contain the same number of chromosomes as present in the body cells of the plant, then, at fertilisation, the number will be doubled for every generation. The chromosome number of the species will not be constant and consequently every generation of the plant will be widely different from the previous one. This will lead to unprecedented consequences. Therefore, a contrivance by which the number of chromosomes in the gametes is reduced to half the number in body cells, exists in nature, viz., meiosis. When pollen mother cells (PMC) and egg mother cells (EMC) divide, they undergo meiosis and form tetrad of pollen grains or embryo sac initials with n chromosomes. At fertilisation 2n is restored.

In addition to restoring the original somatic number (2n) characteristic of the species, meiosis makes it possible for the characters of father and mother to reshuffle themselves in the grand-progeny. This takes place by the crossing over of chromosome segments in the pachytene of prophase of the first division.

SECTION II

HISTOLOGY

SECTION III

PHYSIOLOGY

HISTOLOGY

CHAPTER XII

TISSUES AND TISSUE-SYSTEMS

Tissue.—Among plants it is only the lowest forms of life like the bacteria, fungi and algæ that possess a simple type of structure. The body is either unicellular or multicellular. Some of them are unicellular, and they remain so throughout their life. In such plants all the vital functions are performed by the single cell. The plant body of a multicellular lower plant consists of a number of protoplasts separated by cell walls. All the cells in the plant body are more or less similar in structure and function. In other words, we find similar cells aggregated together and this aggregation of cells is usually spoken of as a **tissue.**

As we ascend from the lower to the higher plants we notice a gradual increase not only in the size of the plant body but also in external organisation. The parts become more complex, numerous, and they have to perform different functions. All the external modifications result from the changes occurring in the cells. The groups of cells constituting the plant body acquire diversity in form, structure and function. In the higher plants the cells, although more or less uniform when they arise, become differentiated into variously constructed kinds of cells, connected by intermediate forms. Hence it is that we find in the organs of plants similar cells associated together in groups, which constitute different kinds of tissues. These tissues may be considerable in amount and be found in unbroken connection extending for some distance only or they may be connected throughout the plant body. The tissues are distinguished from one another by the form, contents, and the walls of their constituent cellular elements.

From the study of the various organs of flowering plants we learn that they are made up of different kinds of tissues, and that the kinds of tissues are definite and limited in number. The tissues of plants fall into two primary classes, namely, the **formative** or **meristematic** tissues and the **mature** or **permanent** tissues.

Meristems.—We know that the embryo or the young plant within the seed consists of cells more or less uniform in structure and form and that all these cells are derived from a single cell by cell division. These cells form a kind of tissue called **meristem** tissue. When the embryo grows into a seedling after germination

differentiation of cells into tissues commences, but the meristematic cells become localised at the tips of leafy branches and root. However diverse may be the form and structure of the various elements that make up the tissues of vascular plants, they are all derived from the embryonic cells located at the tip or growing points of foliage branches and roots. Hence meristematic tissue is also called **formative tissue.**

The aggregate of actively dividing cells, in the apical portion of the vegetative cones of stem and roots constituting the meristem tissue, consists of small cubical cells with very delicate cell walls, abundant dense protoplasm without vacuoles and very large nuclei. The growing point, the young leaves and lateral branches which arise from the embryonic part of the apex consist of meristematic tissue. The apical meristem is continually carried forward by the enlargement of the cells beneath it that have been formed by its own activity, just as a man standing on a brickwall which he is constructing is pushed upwards with each successive layer of bricks.

The vegetative cone of the plumule produces at its apex rudiments of leaves and lateral branches on its sides, and these appear at first as small protuberances. As activity increases in the cells below the meristematic apex, these rudiments of lateral branches get separated and, when leaves, nodes and internodes become differentiated, the rudimentary lateral branches still existing as groups of meristem cells occupy the axils of leaves. Thus it is obvious that all the meristems found at the apices of growing points of all the branches of a plant owe their origin to the meristem of the growing point of the seedling of the plant. So the meristems found at the growing points are called **Primordial Meristems.**

Primary meristems.—In the cells lying below the meristematic cells a certain amount of change becomes apparent. They grow differently and give rise to strands or layers of variously shaped formative cells, which at first retain the general characteristics of meristem cells.

It is possible to distinguish in the vegetative cones of at least some plants three distinct regions, namely, **dermatogen, periblem** and **plerome.** (Fig. 158). Dermatogen is the outermost layer of cells covering the vegetative cone, the developing leaves and buds. The cells of this layer continue to divide only by walls at right angle to the surface. In other words, division takes place only by anticlinal walls. If this layer is followed downwards it will be found to be continuous with the epidermis of stem and leaves.

Therefore we have to conclude that dermatogen is epidermis in the embryonic stage. In all plants in which the epidermis is one

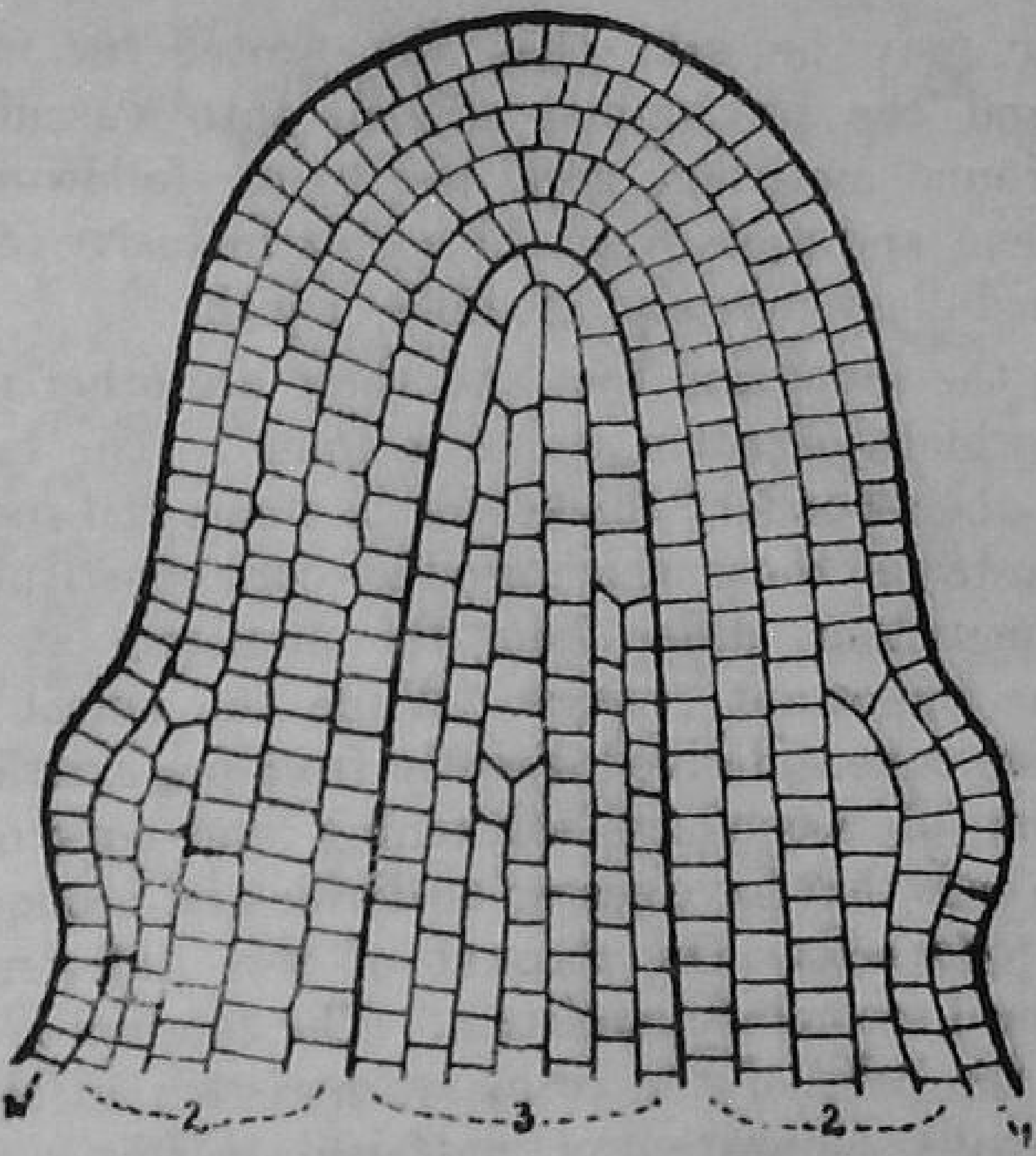


Fig. 158. A diagram of longitudinal Section of the growing potnt of the stem *Hippuris*. (1) Dermatogen. (2) Periblem. (3) Plerome.

layered it increases in superficial expanse to keep pace with the increase in the tissues within. The central cylinder of the vegetative cone is called the plerome and the layers of cells lying between the dermatogen and the plerome constitute the **periblem.** Sharp distinction between the periblem and the plerome exists only in certain plants, while in others it does not exist. In certain plants the distinction becomes apparent lower down. **The periblem gives rise to the cortex including the endodermis and the stele is derived from the plerome.**

The primary meristems are sometimes classified in another way. The meristem which is outermost and divides always radially gives rise to epidermis. This is termed **Protoderm** (=Dermatogen). The protoderm is single layered and surrounds the other two primary meristems to be mentioned below.

Within the cylinder formed by the protoderm, lies the mass of meristematic cells. This gives rise to the ground tissue and hence is termed **ground meristem.**

Imbedded as it were in the ground meristem, strands of long cells are found in the places where the vascular bundles are

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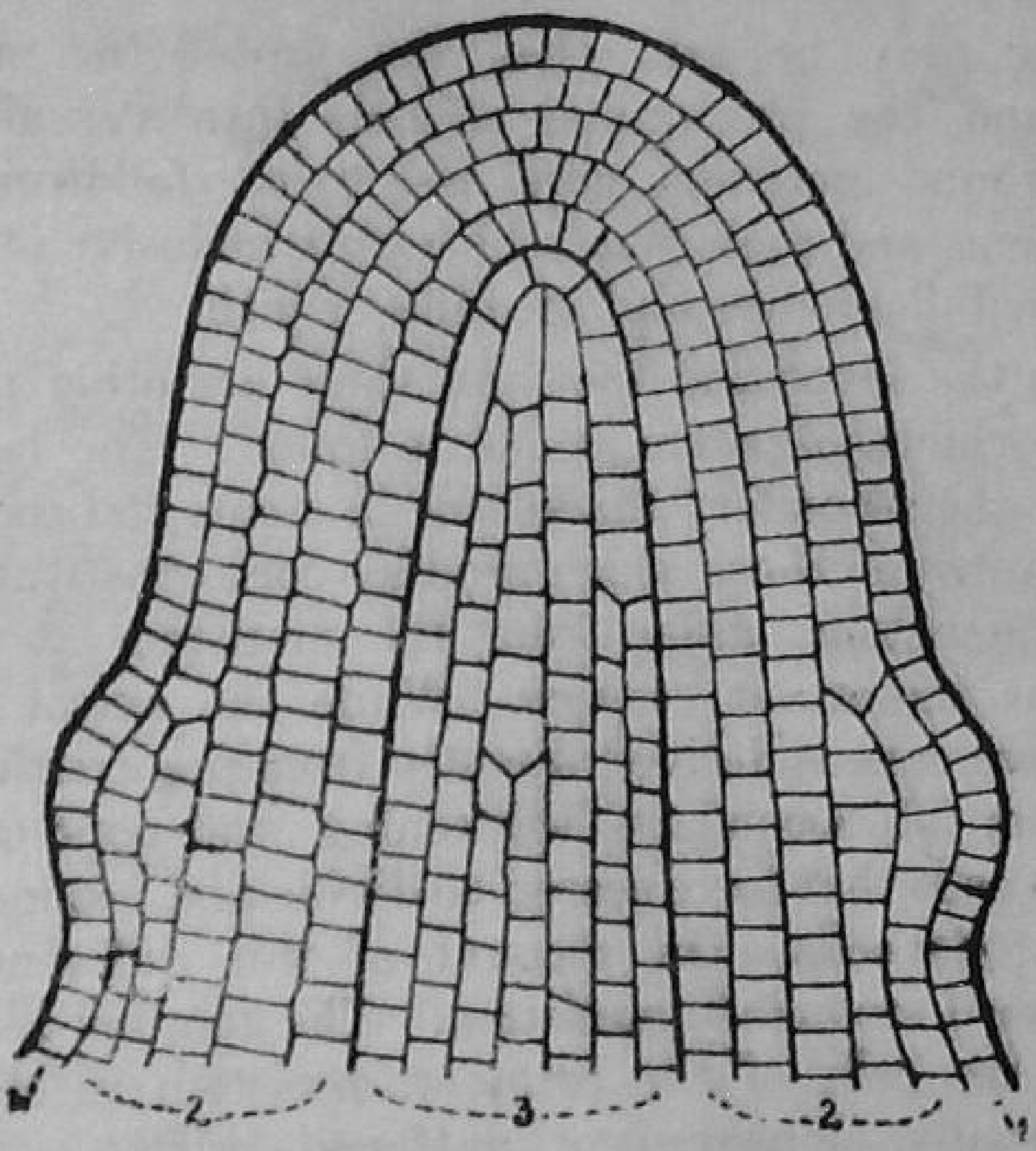

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Imbedded as it were in the ground meristem, strands of long cells are found in the places where the vascular bundles are

developed later. These strands are termed **Procambial Strands.** The procambial strands mature into the xylem and phloem elements of the vascular bundles.

Thus it may be said that the protoderm matures into epidermis and the procambial strands into vascular elements while the ground meristem, gives rise to the following permanent tissues in stems and roots, viz., the cortex inclusive of endodermis, pericycle, medullary rays and medulla or pith.

Besides the shoot and root tips there are other parts also in a plant in which meristem tissue is found. The layers of cells which cause the secondary thickening in stems and roots of dicotyledonous plants and those which produce cork constitute meristems. But these meristems differ from the meristem at the growing point in one important respect. While the apical meristem of the vegetative cone is derived directly from pre-existing meristem, the cambium of secondary thickening and cork cambium are formed from cells that have ceased to divide and become permanent parenchymatous cells. On account of this difference cambium must be termed secondary meristem. The cambial cells, however, differ from the cells of the primary meristem in shape. These cells are usually elongated or flattened prisms.

Permanent Tissues.—All cells and tissues other than meristem come under this head. Permanent tissues consist of cells that are larger with freely vacuolated protoplasm. In some cases the cells become dead losing the protoplasm. The cell walls are variously thickened and also chemically altered.

Tissues or tissue systems included under permanent tissues are the following :—

1. Epidermal tissue, 2. Parenchymatous tissue, 3. Cork tissue, 4. Mechanical tissues, 5. Vascular tissues, 6. Laticiferous tissues and 7. Glandular tissues.

1. Epidermal Tissue.—The epidermis is the outer-most layer of cells covering the exterior of the plant body, especially the stem and leaves. As already stated this is derived from the dermatogen (Protoderm) and it forms an excellent protective tissue against loss of water, parasitic fungi and mechanical injury. In many plants the epidermis is the only protective tissue existing in herbaceous plants and in herbaceous parts of woody perennials. In the vast majority of plants the epidermis consists of only one layer of tabular or more less elongated cells without intercellular spaces between them. The lateral walls of the epidermal cells are undulating. So long as these cells are alive they contain protoplasm which is generally reduced to a very thin layer with

the vacuoles filled with coloured or colourless cell sap. Except in ferns and in some shade loving plants, chloroplasts do not occur in the epidermal cells. Very often the epidermal cells serve as water reservoirs. The many layered epidermis occurring in *Nerium* and *Ficus* are efficient water reservoirs. In the epidermal cells of many species of *Ficus* crystals of calcium carbonate or cystoliths are commonly found. This has already been referred to on page 150.

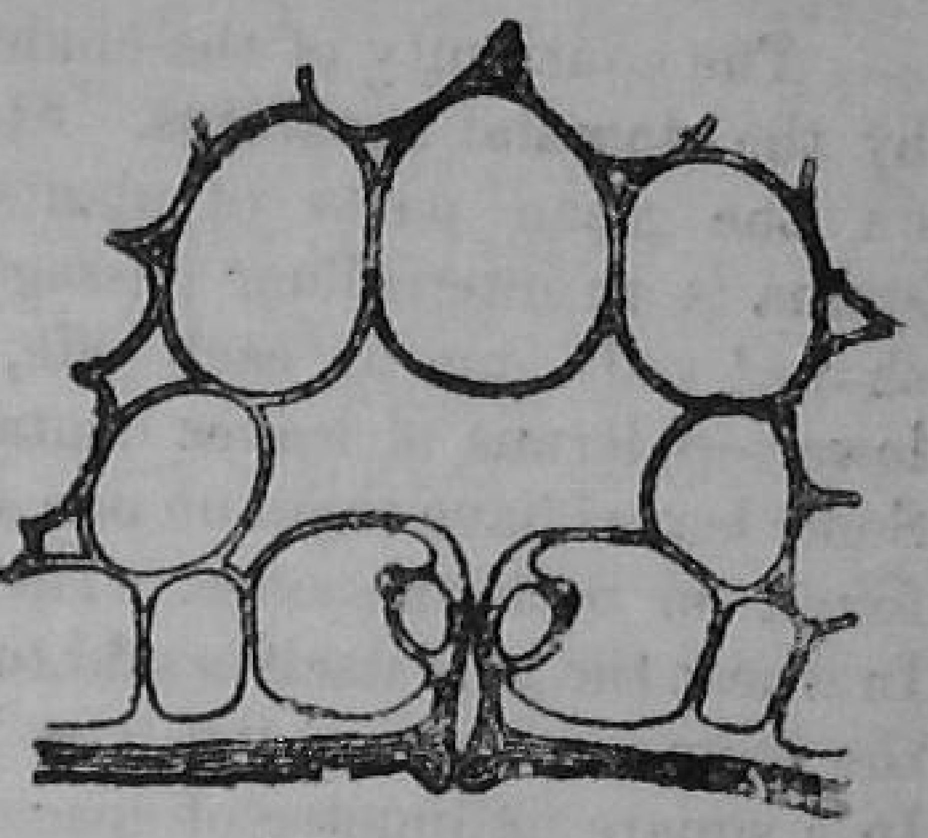


Fig. 159. Epidermis of *Aloe* leaf showing cuticle and stomatal apparatus.

The outer walls of the epidermal cells which last for a considerable time are usually thickened. This thickening is caused by the apposition of cellulose layers, the outer of which usually becomes more or less cutinised. In addition to this thickening, sometimes a continuous cutinised film, called the **cuticle**, is found covering the outer walls of these cells.

In some plants wax may be found deposited on the cutinised layers of the epidermis. The so-called bloom on the stems and leaves, as in castor, sugarcane and in fruits as in grape is due to the deposit of wax. In consequence of the deposits of wax, water will flow off the epidermis without wetting it. The covering of wax may be in the form of grains, small rods or crusts. Occasionally the walls of epidermal cell are infiltrated with silica, as in some Gramineæ. By this deposition the mechanical strength of the outer walls is increased. In Equisetums the silicification is very great and the pericarp of *Coix lachryma-jobi* is as hard as opal.

The cuticle and cuticularised layers are almost impermeable to water and gases. Therefore, the outer walls of the epidermal cells bearing cuticularised layers and cuticle prevent the loss of water by evaporation. In xerophytes the cuticle as well as cutinised layers are very prominent in the epidermis (Fig 159).

In spite of the cutinisation and thickening of the epidermis, comparatively speaking, it is to be considered only thin. Therefore, it may be thought ill adapted to withstand mechanical injury. But considering the fact that epidermal cells are small and that the radial walls are very numerous and close, any mechanical impact will be borne by the radial walls very effectively. Furthermore, the outer walls of the epidermal cells generally

curve outward and this also is advantageous. When the outer wall is silicified the walls become more resistant.

The continuity of the epidermis is interrupted here and there, by the **stomatal apparatus.** Stomata are found in large numbers on the green parts of plants, **and especially in the leaves.** A stoma is an intercelluar passage or pore with a pair of half-moon shaped cells, one on each side, called **guard cells.** Generally the lower epidermis of leaves contain the largest number of stomata. Some leaves have them on one side only and in others they may be found on both the sides. The largest stomata occur in grasses. In wheat the pore itself is said to vary from 0.007mm. to 0.038 mm., the stomata measure 0.079 in length and 0.039 mm. in breadth. In a square millimetre of space stomata average from 100 to 300. As examples of leaves having stomata on both sides we may mention *Cucurbita pepo* and grasses. The lower epidermis in the leaves of *Cucurbita* have about 270 stomata in a square millimetre, and on the upper epidermis they average about 30 to a square millimetre. In the leaves of grasses both the sides contain very nearly the same number of stomata. At any rate, there is not very great difference. In the leaf of *Zea Mays* the lower surface has 68 per sq. mm. and the upper 52. The stomata are mainly useful in the matter of exchange of gases.

The epidermis very often bears on its surface outgrowths of various kinds. The simplest outgrowth is the hair, which is merely a prolongation of the epidermal cells. This is either unicellular or multicellular. In young buds of some plants numerous long hairs form a more or less thick coating, which protect the buds against a too rapid evaporation of water. Some plants have glandular hairs, others branched or stellate hairs. Occasionally the hairs get infiltrated with carbonate of lime or silica and become stiff bristles. Stinging hairs and scales also occur in the epidermis of some plants. In some plants prickles also are found but they are not derived solely from the epidermis. A portion of the sub-epidermal tissue also takes part in their formation.

2. **Parenchymatous Tissue.**—Most of the body of a herbaceous plant and the herbaceous parts of a woody plant consist of cells with thin cellulose walls and vacuolated protoplasm. Such cells are called parenchymatous cells, and an aggregation of these, the tissue parenchyma. In shape the cells may be iso-diametric or elongated and of various shapes. Intercellular spaces occur in parenchyma. The cytoplasm may contain chloroplasts or leucoplasts according to the position the cells occupy in the plants.

As the cells of this tissue are living cells, they serve a variety of functions. They carry on the most important vital processes occurring in plants, namely, preparation, conduction and storage of nutritive materials, storage of water and respiration. They also contribute towards mechanical strength, as they maintain their turgidity. Parenchyma in which the cells are abundantly provided with chloroplasts, as in leaves, is often spoken of as **chlorenchyma.** When numerous large intercellular spaces are found in parenchyma as in aquatics it is termed **aerenchyma.**

3. Cork Tissue.—From its very nature the epidermis cannot be expected to become a permanent protective membrane although it is known to persist for a number of years in some species of *Viscum* and *Acer.* When the epidermis is no longer living and functionally not active, the tissues are protected even more efficiently by suberised cells or cork tissue. (Fig. 160, 161).

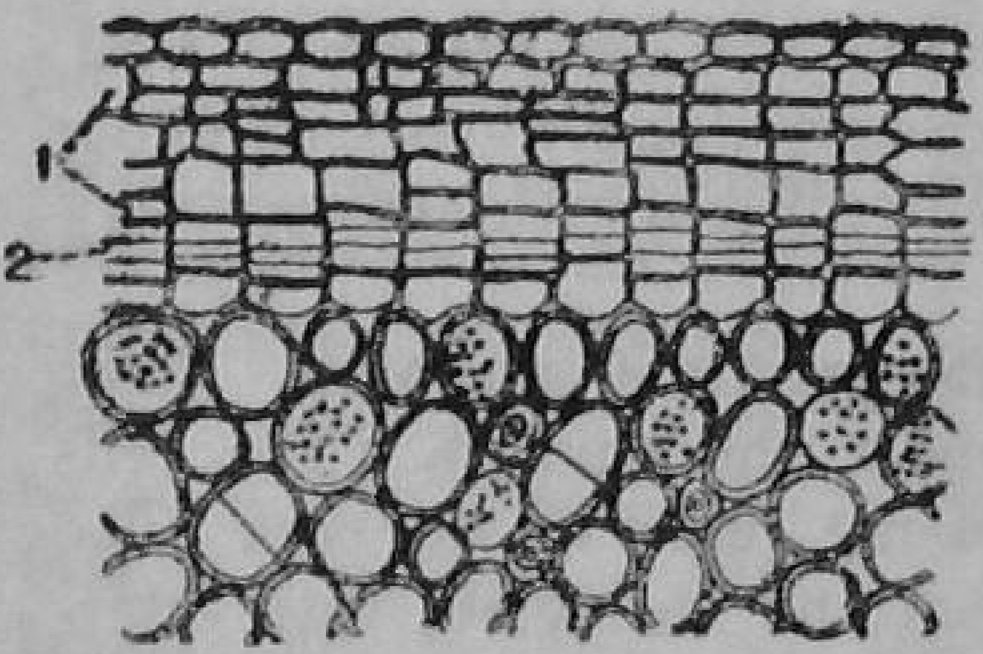


Fig. 160. Formation of Cork in a very young stem of *Jatropha.* 1. Epidermis, 2. Phellogen, 3. Latex tube.

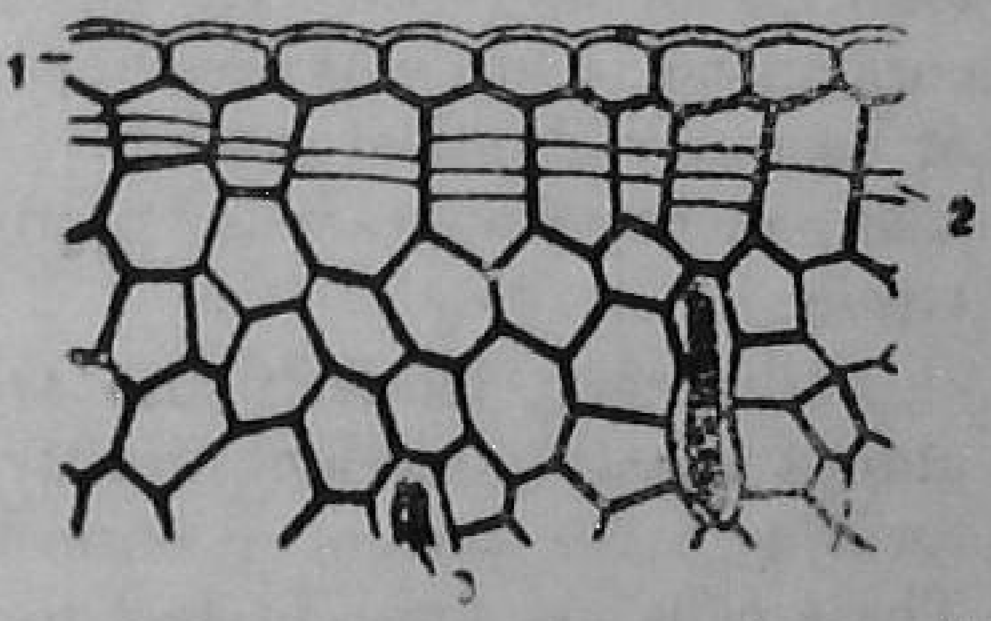


Fig. 161. Formation of Cork in an old stem of *Jatropha.* 1. Cork cells, 2 Phellogen.

While the epidermis is always a primary permanent tissue, the cork is always a secondary tissue, and is developed from a secondary meristem, formed in the cells of the cortex, either superficially or deeply or from pericycle. Some of the parenchymatous cells of the cortex or pericycle begin to divide and this forms the secondary meristem known as **cork cambium or phellogen.** An initial layer is always present in the cork cambium.

As a rule, the initial layer of cork cambium gives rise to cork cells externally. In some plants it also produces cells internally, thus adding to the cortex some more layers of cells. These new layers form the **phelloderm** or secondary cortex.

The cork cambium, cork and the phelloderm make up together what is called the **Periderm** or **bark.**

Cork begins to form only after a certain amount of secondary thickening has taken place. The appearance of brown colour

in stems is an indication of the formation of cork. Cork forms where the epidermis has been thrown off, or where living parenchyma has been exposed by wounds.

When fully developed cork consists of rows of cells forming closely packed tiers without intercellular spaces. Cork cells have a flattened prismatic form with thin walls. In the cell wall the middle lamella is lignified and the superficial layers alone are suberised. Although very thin, the cell walls of cork cells are impervious to both air and moisture. As cork tissue is many layered, it is more efficient as a protective membrane than epidermis, both against loss of water and mechanical injury. Air being a bad conductor, the cork tissue which consists of cells with plenty of air in them protects the inner tissues against injuries that might result from sudden changes in temperature.

Lenticels.—The cork tissue is a continuous layer, except where lenticels occur. Lenticels are formed simultaneously with the cork tissue. On stems they appear as slightly swollen, round, oval, or narrowly elliptical spots or excrescences, and when seen under a lens a lenticel appears as a narrow slit, filled in with some powdery tissue.

Like cork, lenticels also are formed from phellogen. They almost always develop directly under the stomata. The cells formed in the case of a lenticel do not resemble the cork cells. These cells are more or less rounded and lie loosely with intercellular spaces. These are termed complementary cells. In fact a lenticel is nothing but a group of parenchymatous cells arranged in a loose manner. As new cells are formed regularly from the phellogen at the base of the lenticels they remain for years and may grow to a large size. Besides the loose cells there are also found sometimes intermediate bands, shutting off the loose cells from the layers below. These closing layers also ultimately get ruptured. The cell walls of the loose cells are not usually suberised, although the cells of the closing bands are suberised or lignified. The phellogen of the cork and that of lenticels join laterally and become continuous.

Lenticels are obviously intended to facilitate the ingress and egress of gases. How this is rendered possible will be explained later.

4. Mechanical Tissues.—For the proper performance of their functions the parts of plants must have a definite form, and for the maintenance of this form turgidity caused by the presence of water in the tissues is essential. But, however, water alone cannot be depended upon for conferring the necessary rigidity,

since it may be lost by evaporation. As a compensation for this, special mechanical tissues are developed. They are mainly **collenchyma** and **sclerenchyma.**

(i) **Collenchyma.**—Parts of flowering plants undergoing development and growth consist mostly of parenchymatous tissue and therefore, there would be turgidity on account of the presence of water. Such parts may also be elongating actively. These parts are strengthened further by the formation of collenchymatous tissue (Fig. 162). This tissue is always developed peripherally beneath the epidermis and just below the surface of herbaceous parts, such as midribs of leaves, petioles and young shoots, and it does not occur in other places. At first it consists of a few layers but it goes on increasing with the growth of the stem. It forms a continuous layer in some cases, and in others it exists as isolated strands.

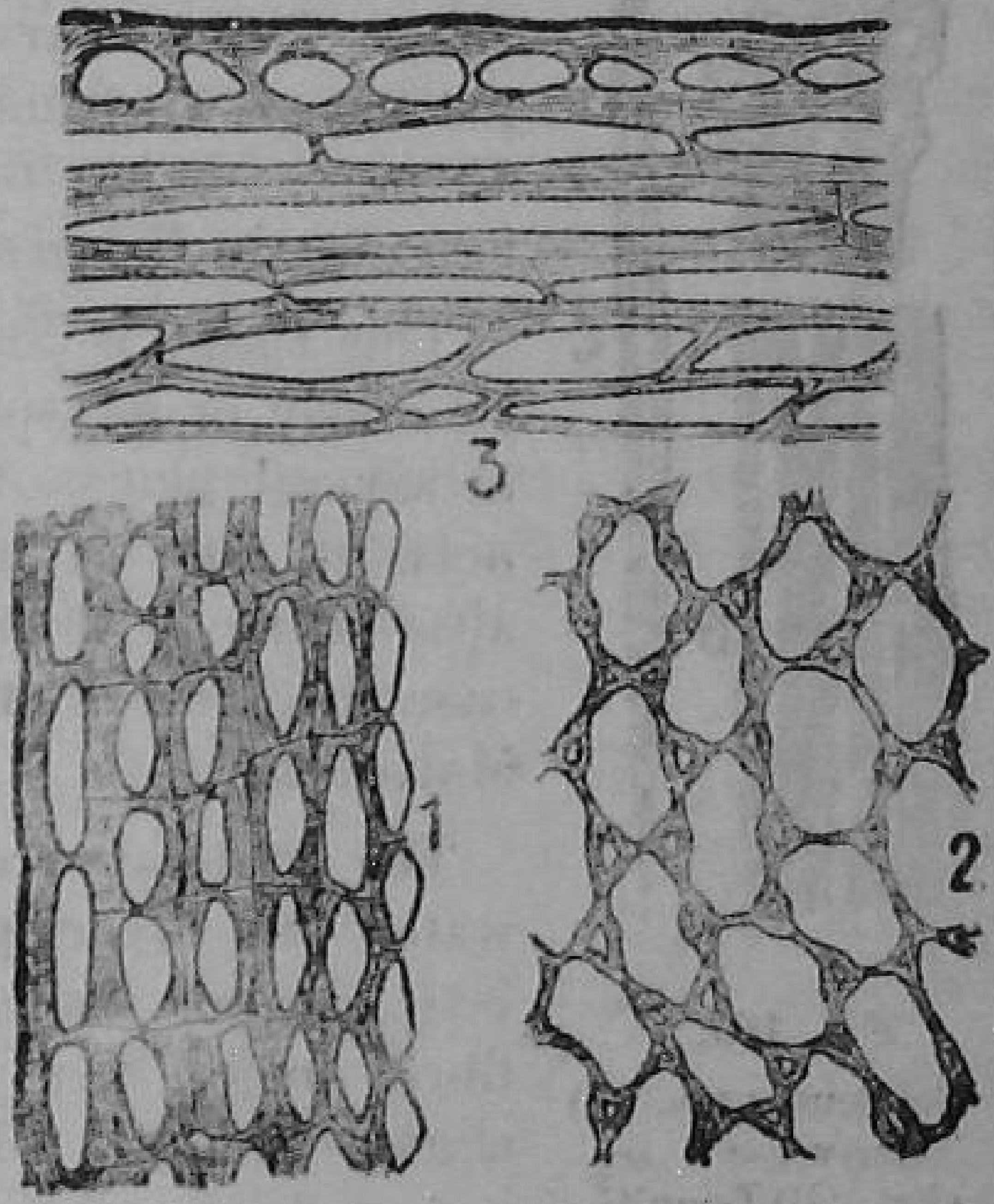


Fig. 162. Collenchyma. 1 & 2 Transverse section, 3. Longitudinal section.

Special characteristic of collenchyma is that it consists of living cells whose walls are greatly thickened, especially at the corners where the cells meet; highly refractive and silvery white. The thickening material is **Cellulose.** Sometimes the thickening is so great, as to completely obliterate the cell cavity. This tissue owes its origin to the parenchymatous cells of cortex.

The chief function of collenchyma is to give mechanical strength to the parts of the stem still growing in addition to being elastic. The great thickening of the cells affords the necessary strength, whilst the living contents enable the cells to grow and keep pace with the increase of tissue within.

(ii) **Sclerenchyma.**—Just as collenchyma is the typical mechanical tissue of parts still elongating, sclerenchyma is the mechanical tissue characteristic of fully grown parts of the plant. This tissue is specially intended to give strength to parts that have ceased to grow in length. The constituent elements of this

tissue are fibres which are narrow, elongated and spindle shaped with pointed ends and without protoplasm. In transverse sections they are polygonal. Fibres are dead cells with greatly thickened walls, consisting of layers of carbohydrates which are lignified (Fig. 163). The walls may have simple pits. In length these fibres vary, although they average between 1 to 3 mm. In flax they are 30 to 40 mm., about 70 mm. in stinging nettle and 220 mm. in *Bohemeria nivea* (China grass).

Fig. 163. Sclerenchyma. (A) Transverse section, (B) Longitudinal section, (C) A single fibre in longitudinal section.

This tissue is found in the stem either continuously or as isolated strands. In the cortex of several plants it forms a plexus, or a regular network. It is not unusual to find them alternating with phloem masses. This is the case in most stems of plants of the family Malvaceæ.

The vertical elongation, lignification of the walls, the tapering ends and the very close interlacing to form bundles so characteristic of fibres make them not only strong but also slightly elastic. The main use of sclerenchyma is to afford sufficient strength to the members in which it occurs.

(iii) **Sclerotic cells** or **stone cells** result when cells undergo thickening without elongating very much. These are characterised by very great thickening appearing as distinct striations and by the possession of very conspicuous pits, some of them being branched. They occur in the cortex, pericycle, and the pith, either singly or in masses. In the hard parts of fruits like Guava and Pear and seeds like Date they are abundant. In fact the hard parts consist of stone cells (Fig. 164).

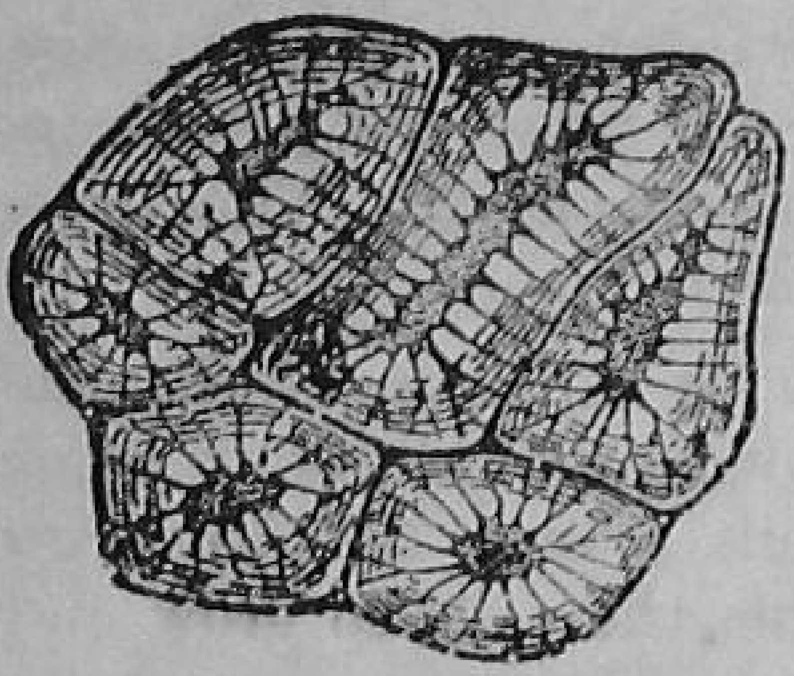


Fig. 164. Sclerotic cells.

5. Vascular Tissue.—With the growth of the parts of plants and increase in their size, the need for rapid conduction of water and other substances from one part of the plant to another becomes greater. It is true that a certain amount of diffusion can take place in the parenchyma, but even at its best the movement of water through this tissue is but slow.

Special tissues capable of conducting substances rapidly have therefore arisen in higher plants. The main elements of which these tissues are composed are mostly elongated in the direction of conduction, and they are in the form of tubes or vessels, hence this tissue is called vascular tissue. Vascular tissues occur in all parts of the plant and they are connected throughout the plant.

Vascular tissues are of two principal types.—**Phlœm** and **Xylem.** They arise from the procambial strands found at the base of the primordial meristem. Vertical rows of parenchymatous cells fuse to form the continuous vessels of xylem and phlœm.

Phlœm.—Phlœm vessels are mainly concerned in the transport of food materials from the leaf to other parts of the plant. Phlœm consists of (i) Sieve tubes (ii) Companion cells (iii) Phlœm parenchyma and (iv) in some cases fibres.

(i) **Sieve tubes.**—When vertical rows of cells fuse to form the conducting vessels, in some of these rows the fusion of superimposed cells is not complete. The transverse or oblique septa between the elongated cells become perforated and the cell walls

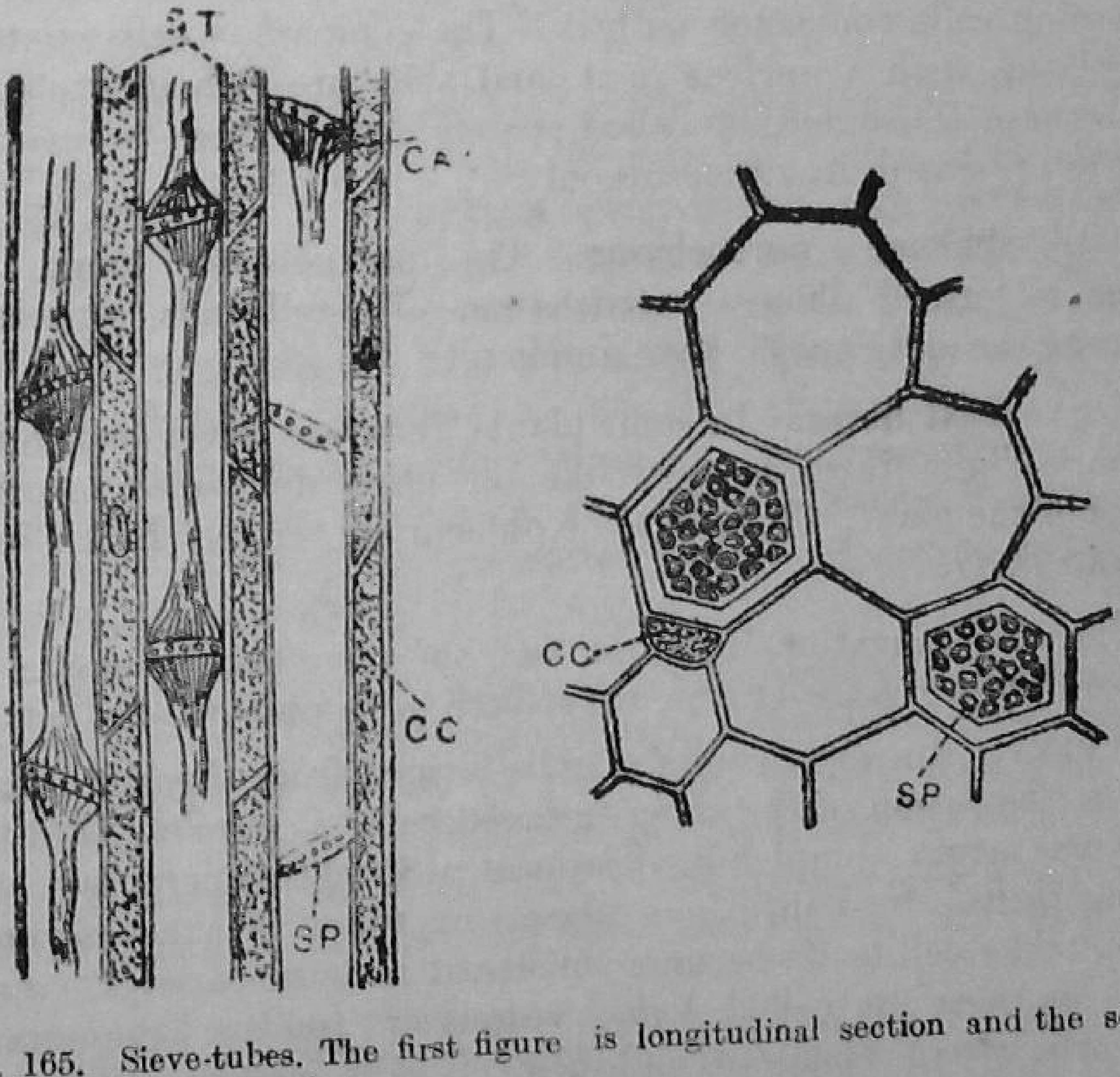


Fig. 165. Sieve-tubes. The first figure is longitudinal section and the second is a transverse section.

(S.T.) Sieve-tube. (CC) Companion cell. (S.P.) Sieve plate.

remain thin and they consist of cellulose. The perforated septa are called **Sieve plates** and the vessels or tubes bearing these plates are called sieve tubes (Fig. 165). Sieve tubes occur in groups mixed up with parenchymatous cells. They form strands running longitudinally and they are the main channels for the transport of proteins and carbohydrates. Each sieve tube consists of a row of long cells with sieve plates. A thin layer of protoplasm is usually found lining the wall and the contents found in the centre of the tube are mucilaginous. Coarse strands of protoplasm pass through the pores of the sieve tubes. The walls remain thin and they consist of cellulose only. When the sieve tubes cease to function, the pores in the sieve plates are closed by the formation of callus on either side of the sieve plate. Callus consists of the carbohydrate **callose** which is colourless and refractive. Callus formation takes place either when the sieve tubes are old or when the plant ceases to grow for any period. The plants in regions with extremes of cold during winter cease to grow during the winter months. The sieve plates are temporarily closed by the deposition of callose. The callose is dissolved out when the plant begins to grow in the following spring.

(ii) **Companion cells.**—Each sieve tube has one or more companion cells connected with it. The companion cells contain protoplasm with a nucleus in it and they are rich in proteins. Hence these are sometimes called protein cells. These companion cells are present in Angiosperms only.

(iii) **Phloem parenchyma.**—The parenchyma found in phloem is termed phloem parenchyma. The cell walls, especially adjoining the sieve tubes, bear simple pits.

(iv) **Bast fibres.**—In some plants fibres are developed in the phloem. These fibres are just like the fibres developed in other regions of the plant. Fibres in the phloem are termed **Bast Fibres** or HARD BAST.

The above mentioned tissues, *viz.*, the sieve tubes, companion cells and phloem parenchyma are spoken of as phloem elements.

XYLEM.—In certain rows of cells formed from the procambial strands, the fusion of the super-imposed cells is complete, and the transverse septa completely disappear. So the superposed cells become transformed into long vessels or tubes with a continous cavity. The cell walls become thickened in various ways. Such vessels as these are called *Xylem* vessels or *trachea*. Sometimes single cells become elongated and their cell walls become thickened. Such are called *tracheids*.

Xylem consists of (i) *Tracheids*, (ii) *Trachea*, (iii) *Wood parenchyma*, and (iv) *Wood fibres*.

(i) TRACHEIDS.—These are elongated single cells with lignified walls. Generally their walls bear bordered pits. Tracheids are the only type of xylem conducting cells met with in some lower plants such as conifers and ferns. In these plants, the tracheids not only function mainly for conducting water but also give strength to the plant on account of the lignification of their cell walls.

(ii) *Trachea.*—In the case of Angiosperms, trachea or the xylem vessels are the main channels for the conduction of water and nutrient salts in solution. The walls of these vessels are usually thickened, although the thickening is never uniform. Vessels in which the thickening is in the form of separate rings of lignified substance, one above the other, are called **Annular Vessels.** If one or more lignified bands are found running round and round in the vessel through its entire length, it is termed a **Spiral Vessel.** If the lignified thickened portion is in the form of a network, then the vessel is called a **Reticulated Vessel.** When the thickening involves the greater part of the cell wall leaving small areas here and there unthickened the vessels are called *pitted vessels* and the areas not thickened are the **Pits**. (Fig 166). Pits are varied in shape. They may be circular, oval or elliptic. In some vessels the pits are transversely extended and stand one above the other. Such **vessels are called Scalariform Vessels**. Generally the pits are **Bordered** in pitted vessels and bordered pits are more common in lower plants like Gymnosperms and Ferns.

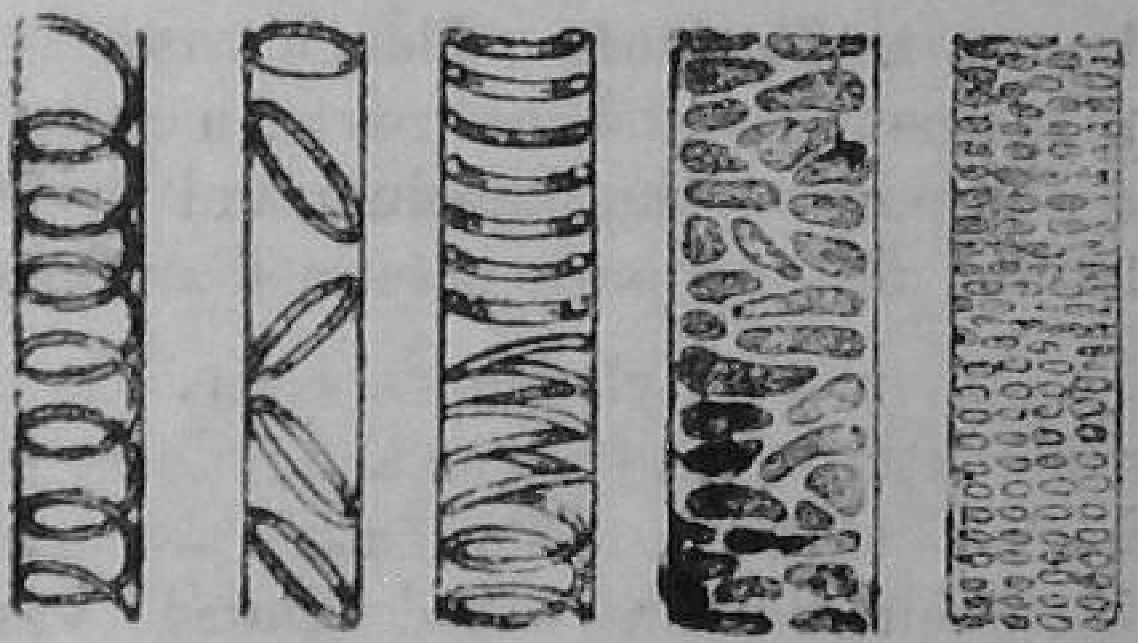


Fig. 166. Vessels with different kinds of thickenings. (1) & (3) Spiral. (2) Annular. (4) Reticulated (5) Pitted.

(iii) WOOD PARENCHYMA.—Parenchymatous cells in the xylem are termed wood parenchyma. While the xylem vessels and tracheids may consist of dead cells, wood parenchyma is a living tissue. When secondary wood is developed, the walls of parenchyma may become lignified. The parenchyma then, along with the tracheids, trachea and fibres adds to the strength of the region.

(iv) WOOD FIBRES.—These are ordinary fibres associated with xylem.

VASCULAR BUNDLES.—As a rule, both the conducting tissues, namely, sieve tubes and xylem vessels or trachea, occur as strand or bundles traversing the whole of the plant body. Both these bundles occur together and they are always associated one with the other. Hence the strands or bundles are called **Vascular Bundles.** At the growing point below the meristematic tissue and in the plerome there arise groups of cells called **Procambium** or **Procambial Strands**. In dicotyledonous stems the inner portion of the procambium is transformed into xylem vessels and from the external part sieve tube tissue is derived. A small portion of the procambium between xylem and the phloem remains without undergoing any change and retains the power of division. This meristem is known as **Cambium.** Thus a vascular bundle in a dicotyledonous plant consists of three parts, namely, the **Phloem** or sieve tube tissue portion, the **Cambium** and the **Xylem.** A vascular bundle having all these parts is termed an **Open Vascular Bundle.**

In monocotyledonous stems the procambial strands become differentiated into xylem and phloem without any part of it persisting as cambium. The entire procambial strand is used up and these bundles are called **Closed Vascular Bundles** (Fig. 167).

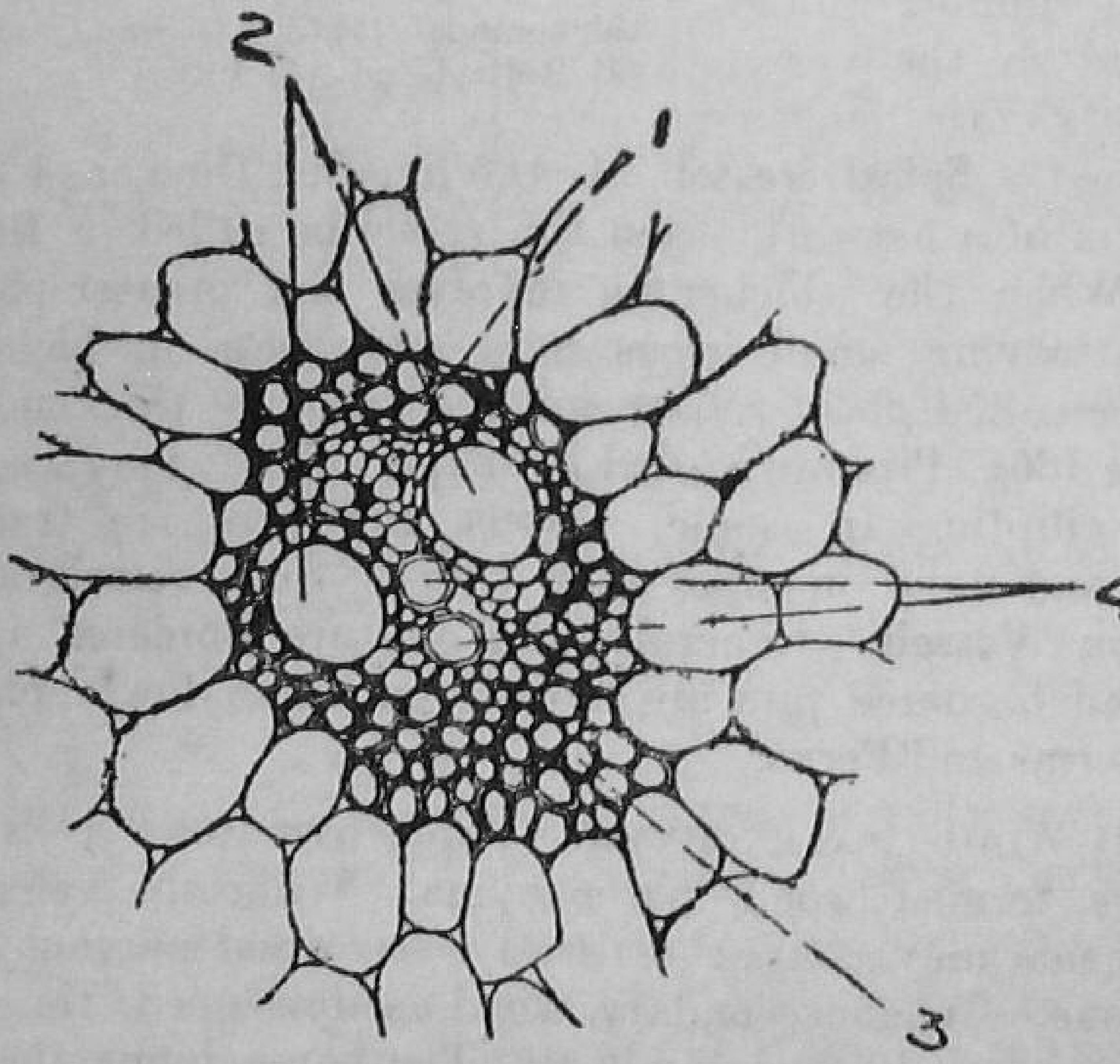


Fig. 167. A closed vascular bundle. (1) Phloem (2) Pitted vessels. (3) Sclerenchyma (4) Annular and spiral vessels.

The bundles of the stems are called **Collateral Vascular Bundles** because the xylem and the phloem are on the same radius one behind

the other. In some stems as in *Cucurbita* and tobacco, phloem occurs on both the sides of the xylem and such bundles are called **Bi-collateral Vascular Bundles.** In the roots of both monocotyledonous and dicotyledonous plants the xylem and the phloem lie side by side on different radii in the primary vascular bundles. These bundles are called **Radial Vascular Bundles.**

All vascular bundles end in the leaves. These descend into the stem from each leaf, and after traversing one or more internodes they branch and fuse with the bundles that enter the stem at the lower nodes. So all the vascular bundles of the stem are continuous. The vascular bundles descending into the stem from a leaf form the **Leaf Trace Bundles.** All the vascular bundles disposed in the form of a ring in the stems of dicotyledonous plants are composed of leaf trace bundles. As the bundles are common to both the stem and the leaf, they are called common bundles. The upper part of the bundle, which runs through the cortex towards the leaf is termed a leaf trace. Within the stem the vascular bundles run parallel to the axis through the internodes, but at the nodes there is a considerable amount of branching and intercommunication of these bundles.

6. Laticiferous Tissues.—When we cut the stems or leaves of the plants *Euphorbia*, *Ficus* and *Lactuca*, there is an exudation of milky juice. This milky juice is usually contained in branched cells or in branching and anastomosing vessels. (Fig. 168). The latex tubes in *Euphorbias*, *Apocynads* and *Asclepiads* are cells developed into branched tubes.

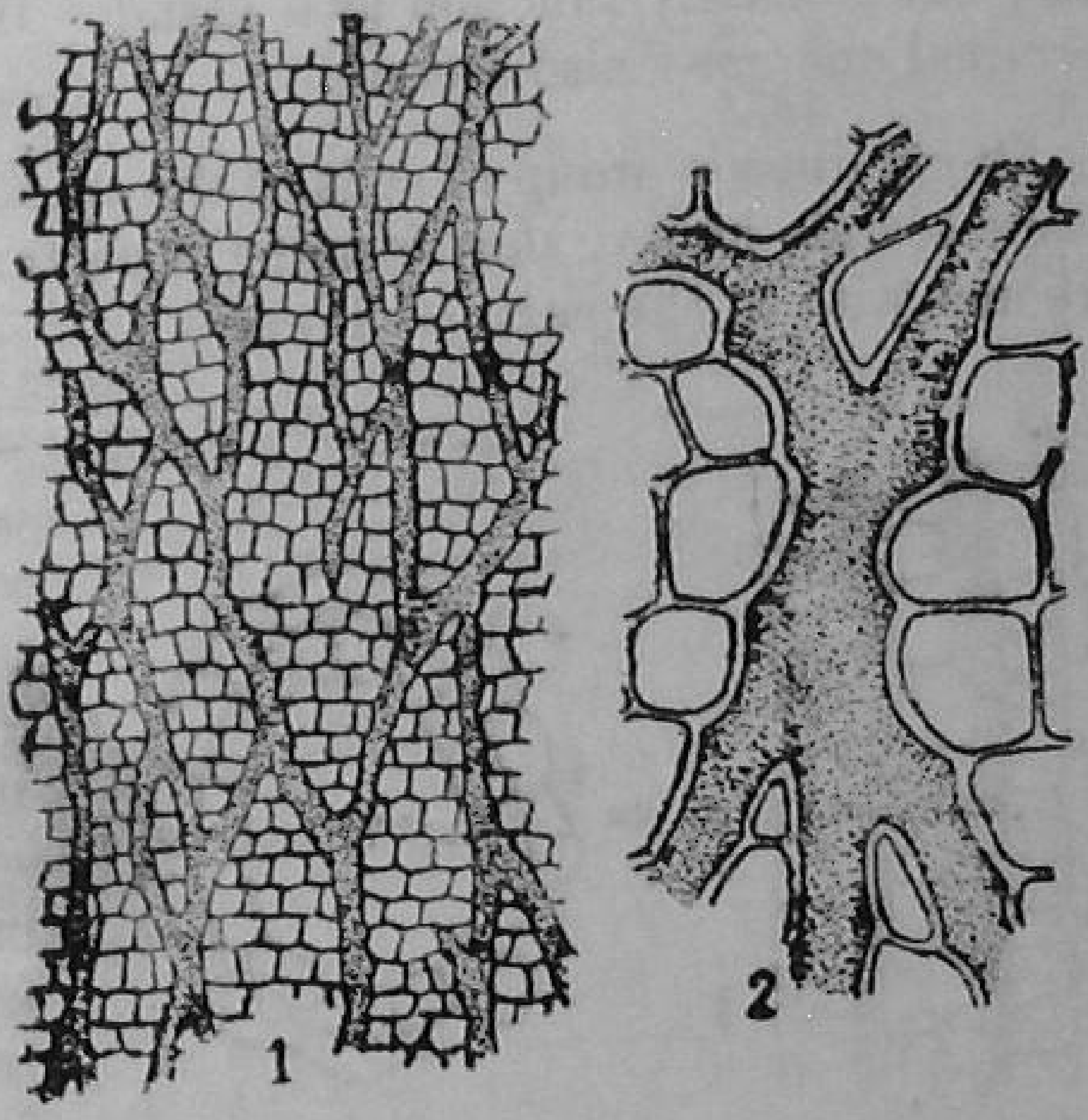


Fig. 168. Laticiferous system : (1) slightly magnified ; (2) highly magnified.

These tubes only branch but they do not anastomose. On the other hand, the latex vessels in *Lactuca* and *Argemone* are true vessels formed by the fusion of cells. These always anastomose and form net works.

Latex is usually a white milky juice, and it is occasionally colourless or yellowish in colour. This liquid contains gums, resins, caoutchouc, fat and wax in emulsion. In some plants enzymes and poisonous alkaloids are also found in the latex. As these substances are of the nature of excreted products, the tubes are often to be regarded as reservoirs of excreted substances. However, occasionally, starch grains and protein grains occur in the latex. In such cases it is probable that latex tubes serve for storage and transport of nutritive material. Coagulated latex is rubber, obtained from plants like *Hevea*, *Manihot braziliensis*, etc.

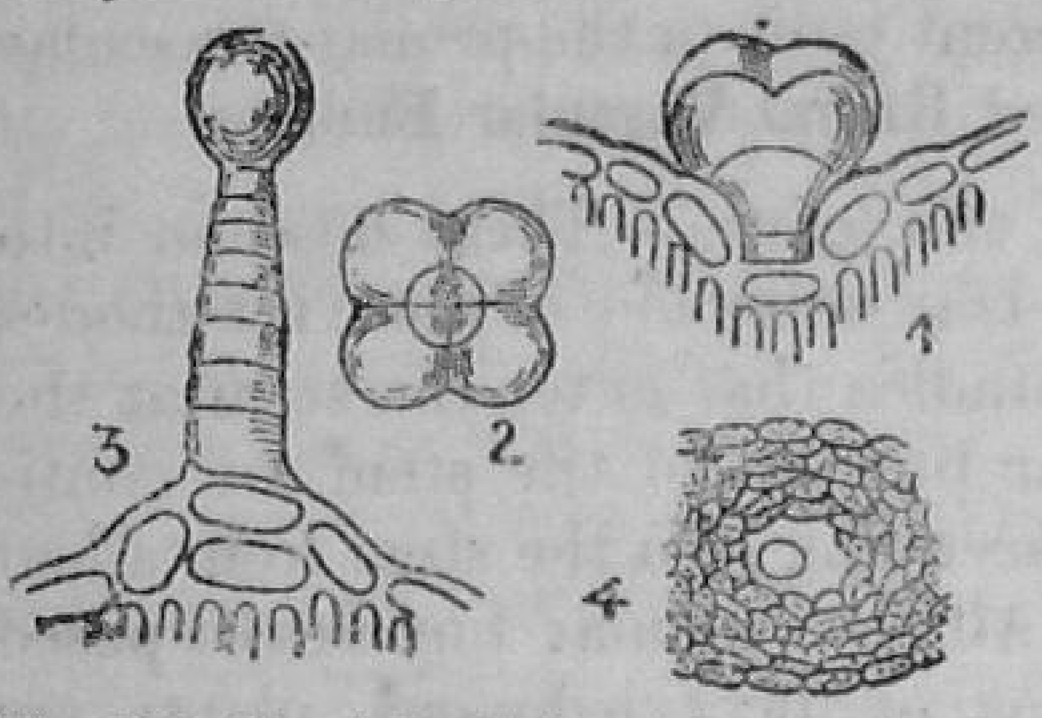


Fig. 169. Glandular hair and oil glands. (1) Side view and (2) top-view of glandular hair of *Ocimum basilicum*. (3) Glandular hair of *Petunia*. (4) Oil gland of *Citrus*

7. **Glandular Tissue.**—This tissue varies very much in structure (Fig. 169). Glandular hairs occurring as outgrowths of the epidermis are of the simplest kind. The terminal cells of such hairs usually function as a gland. But cells, other than the terminal one, may also secrete.

Sometimes a group of cells of the epidermis and sub-epidermal tissue secrete honey, thus forming a nectary. Generally nectaries are met with in the parts of flowers.

There are also cavities or passages formed in various parts of plants in which ethereal oil, gums and resins are secreted. The oil glands seen in the leaves and in the pericarp of the fruits of lime and orange trees are really cavities formed by the destruction of some of the cells. Such cavities are termed **Lysigenous** cavities. Resin ducts or passages also occur in plants and these are formed by the separation of cells first so as to form a slit in the intercellular space and then by further separation it becomes wider (Fig. 170).

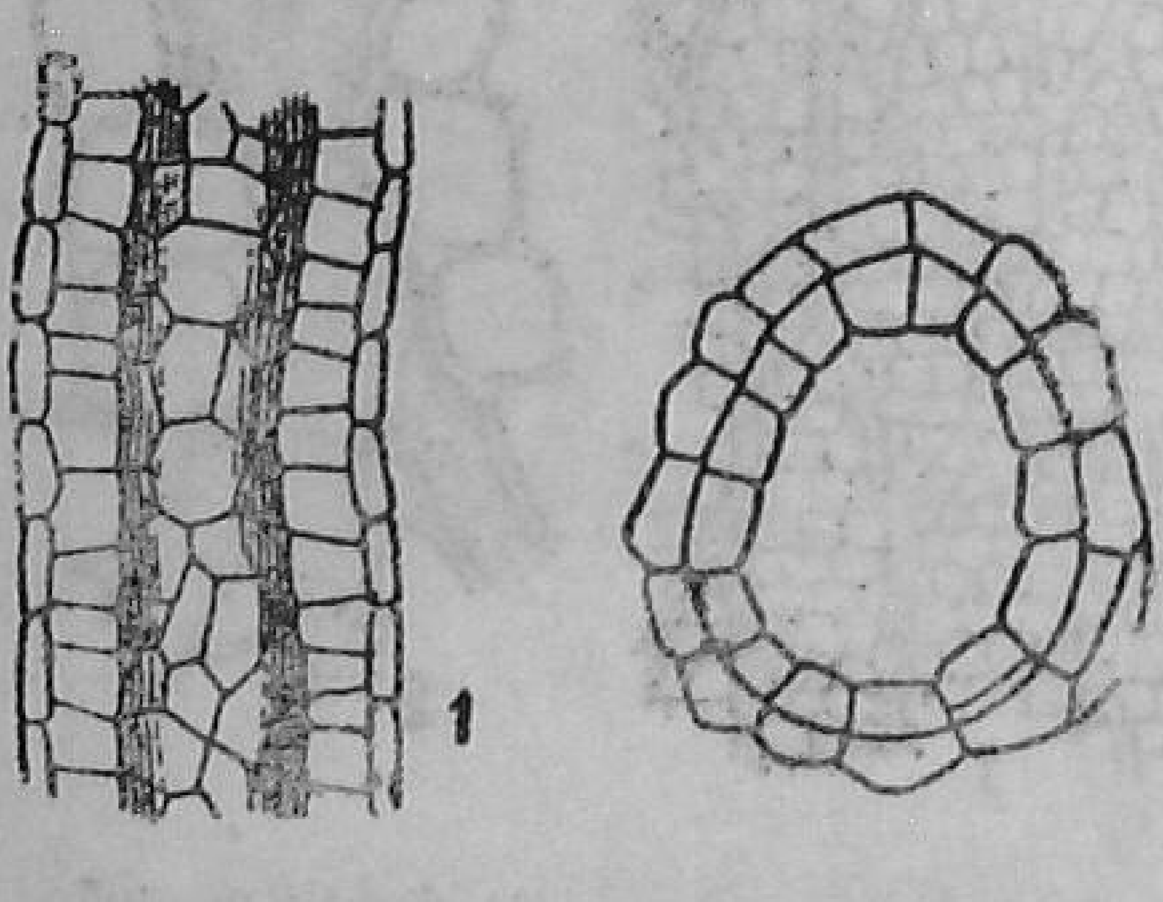


Fig. 170. Resin ducts: (1) longitudinal, and (2) transverse sections.

Resin Ducts occur in the cortex of the stem of *Helianthus*. Such passages as these are called **Schizogenous** cavities or passages.

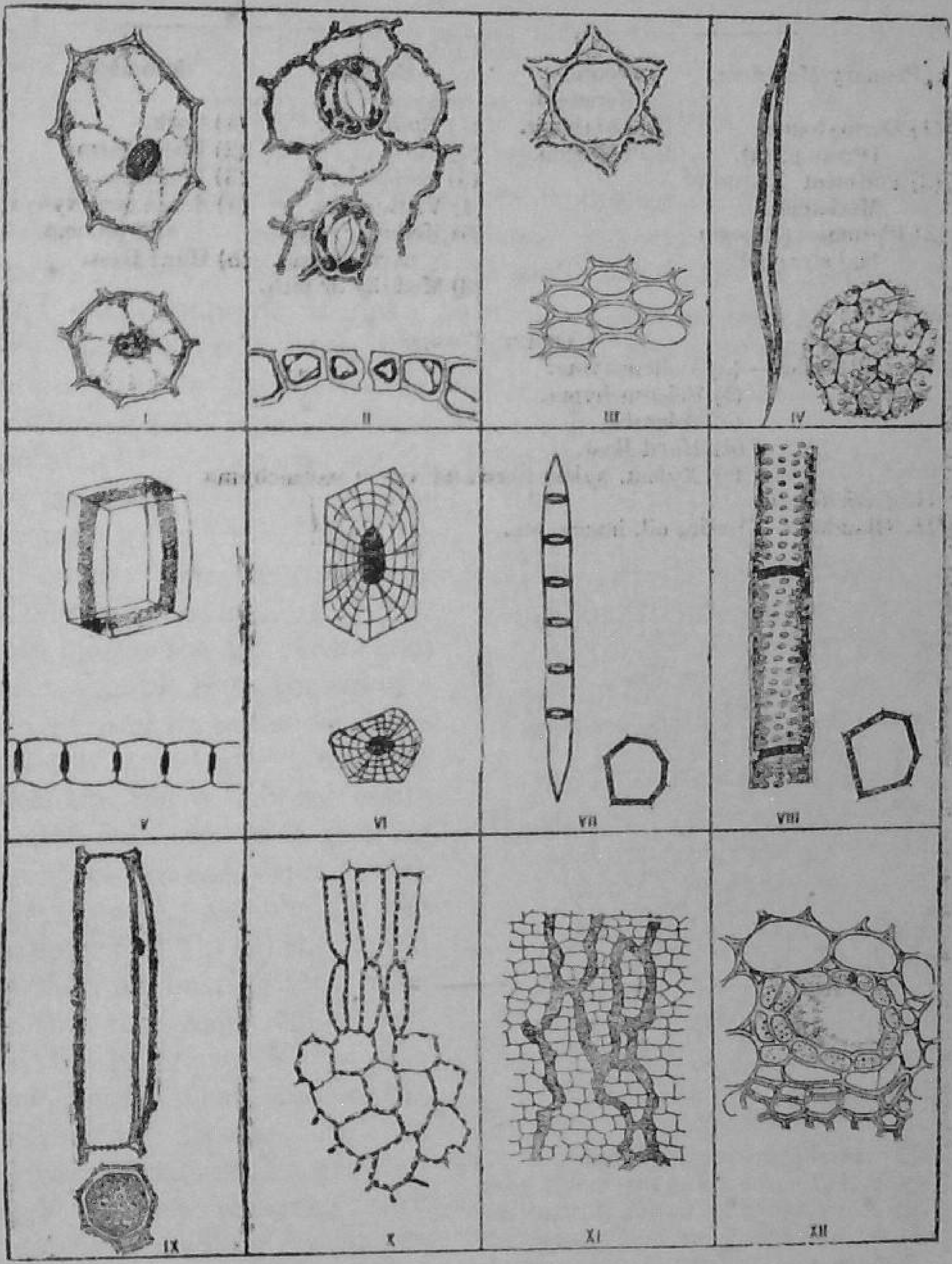


Fig. 171. Types of cells found in different plant-tissues: (Longitudinal and cross-sectional views are given within each square) (i) Parenchyma (ii) Epidermal cells (surface view & cross-sectional view showing stomata). (iii) Collenchyma (iv) Sclerenchyma (v) Endodermal cells (vi) Sclerotic or stone cells (vii) annular thickened trachea (viii) pitted vessels (ix) sieve tube and companion cell (x) Palisade and spongy tissues of leaf (xi) laticiferous cells (xii) glandular cell.

MAIN TISSUES.

- **Formative or Meristematic.**
  - Primary Meristem.
    - (1) Dermatogen (Protoderm).
    - (2) Periblem (Ground Meristem).
    - (3) Plerome (Procambial strands).
  - Secondary Meristem.
    - (1) Cambium.
    - (2) Phellogen.
- **Mature or Permanent.**
  - Primary.
    - (1) Epidermis.
    - (2) Cortex.
    - (3) Pericycle.
    - (4) V. Bundles.
    - (5) Medullary ray-parenchyma.
    - (6) Medulla or pith.
  - Secondary.
    - (1) Cork.
    - (2) Phelloderm.
    - (3) Lenticel.
    - (4) Secondary xylem and phloem.
    - (5) Hard Bast.

OTHER TISSUES.

I. Mechanical—(*a*) Collenchyma.
(*b*) Sclerenchyma.
(*c*) Sclerotic.
(*d*) Hard Bast.
(*e*) Xylem, xylem fibre and xylem parenchyma.

II. Laticiferous.—

III. Glandular.—Resin, oil, honey, etc.

CHAPTER XIII

INTERNAL STRUCTURE OF ROOT

1. **Structure of Root**—*Root tip.*—All roots have pointed tips that are smooth for a considerable distance. A little behind these ends the roots are completely covered by downy root hairs. Above this portion of the root, root hairs are not found and only remnants of dead ones are present. Like the stem the roots also grow in length at their tips by means of their growing points found at their free ends. Every one of these growing points of roots consists mostly of meristem tissue and is protected by a root cap, as otherwise the meristem is likely to be injured. The root cap covers the tip of the root as a thimble does the tip of a finger, and its outer cell walls become mucilaginous making the tip move forward easily in the soil. So in a growing point we can easily distinguish three parts, namely, (1) the smooth root tip (2) the region of the root bearing root hairs or the root hair region and (3) the older portion of the root devoid of root hairs or the conducting region. All the external features of a growing root can be observed very easily in a seedling growing in sand or saw-dust. For this purpose seeds of *Setaria italica* (Tenai) can be raised (Fig. 172)

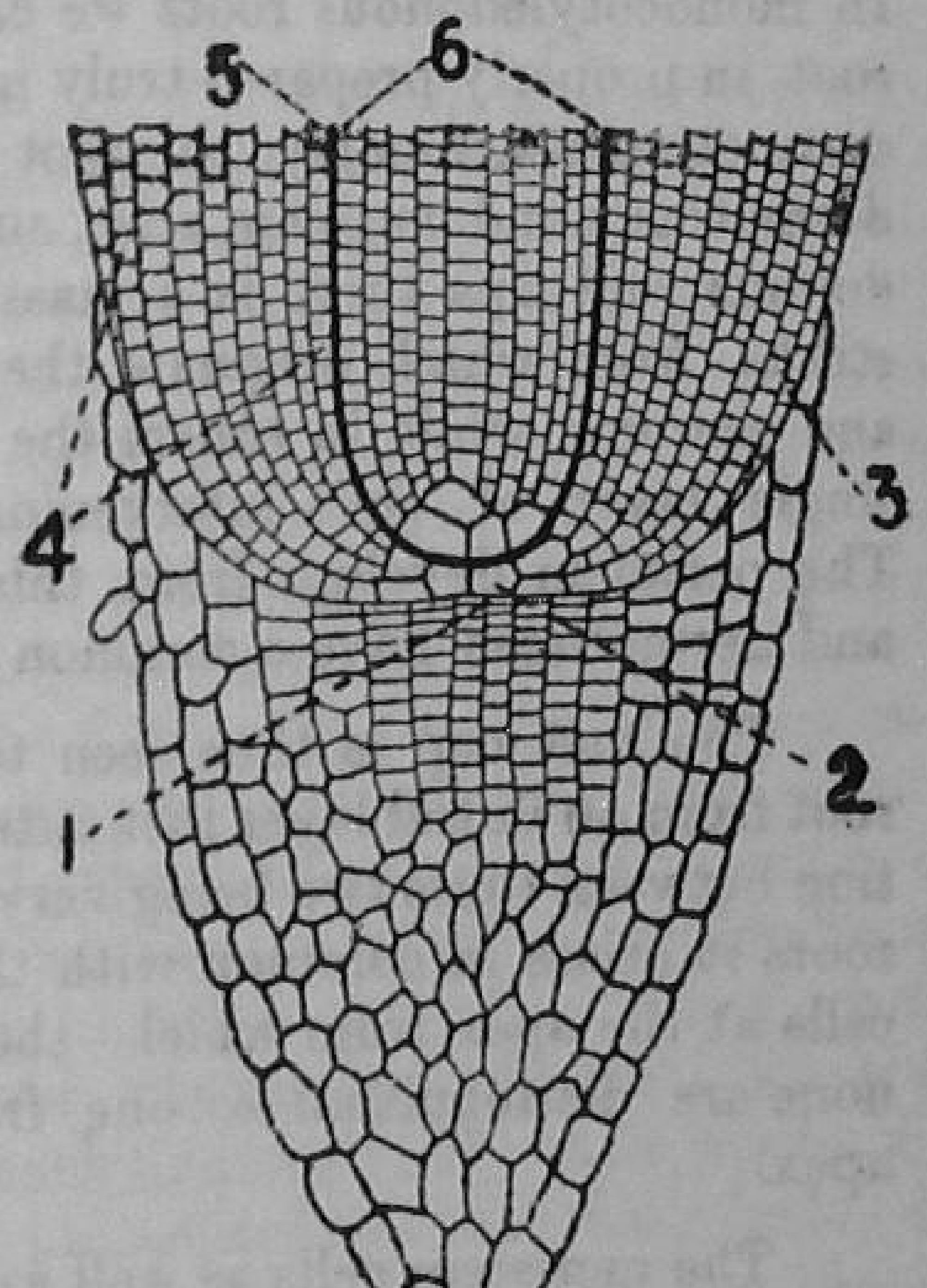


Fig. 172. Longitudinal section of the root tip of a grass root. (1) limit of rootcap (2) initial cells from which the dermatogen and the periblem arise (3) dermatogen (4) periblem (5) endodermis (6) plerome.

The smooth root tip really consists of two distinct regions, namely, the formative region covered by the root cap and the elongating region. The actual growing point in the formative region consists of equivalent meristematic cells that are arranged in regular rows. The origin, development and arrangement at the

apex of the various layers of cells including the root cap are very varied. So it is better to select as types the roots of plants whose structure at the tip is simple, typical and easy to understand. As an example the root tip of any grass may be chosen. If a longitudinal section of the root tip of a grass or any monocotyledon be examined under the microscope, we can clearly distinguish the **Root Cap, Dermatogen, Periblem** and the **Plerome**. At the apex the root cap can be made out very distinctly, as it is sharply marked off from the actual root tip. The plerome is clearly seen in the centre and it ends in a rounded dome. This is covered by the periblem and the dermatogen. These two embryonic regions end in one single layer that gives origin to both periblem and dermatogen. In monocotyledonous roots we can distinguish at the apex of the root, in properly prepared truly median longitudinal sections, three distinct strata, namely, the root cap, the initial layer from which dermatogen and periblem arise, and the plerome. In some dicotyledonous root-tips there is a mass of meristem tissue without any strata, from which originate the root cap, dermatogen, periblem and plerome while in others the plerome is distinguishable with a single layer of cells intervening between it and the root cap. The periblem develops from this single layer, and the root cap and dermatogen have a common origin.

The root cap is thus seen to arise in the monocotyledonous root from an initial layer just outside the dermatogen, the delimitation between these two being very well marked. In dicotyledonous roots it arises in common with the dermatogen or from a mass of cells at the apex from which the other embryonic strata arise, none are distinguishable, one from the other, at the extreme apex.

The meristem cells as well as the permanent cells in the course of transformation need oxygen for their growth. So, for the admission of air, air spaces are formed between the cells. At first the cells get separated at the angles their walls make with each other. These small spaces become united so that intercellular passages run among the cells of every region, and they are of different dimensions in different areas. These intercellular passages become open to the exterior in the upper portion of the plant. This enables the air to enter and circulate through the interior of the tissues. The openings existing in the bark, namely, lenticels facilitate the entrance of air.

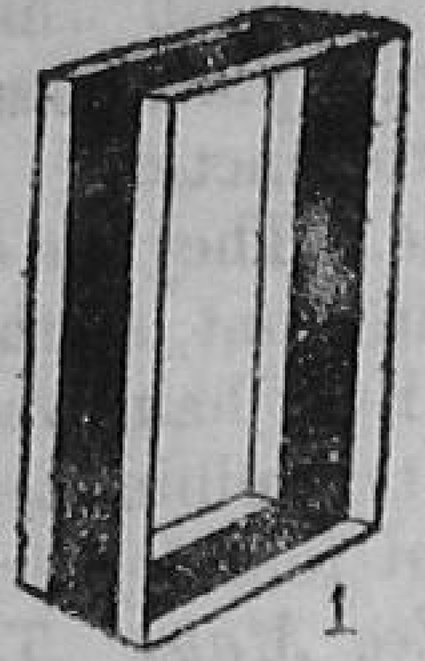
As already stated, root hairs appear at some distance from the root tip in the region of the root, where growth in length has ceased. The root hairs are the tubular protrusions of the epidermal

cells. Each root hair consists of a thin cellulose cell wall which is mucilaginous externally and encloses vacuolated protoplasm, so long as it is in a living condition and continues to function. In general root hairs have only an ephemeral existence. They die off close to the conducting region and new ones arise in front, so that the root hair region may retain its average area. Root hairs vary in length from a fraction of a millimeter to about ten millimeters. They occur in very large numbers averaging about four hundred and twenty in a square millimeter of space in *Zea Mays*. The function of root hairs is absorption of water and fixation in the soil.

Structure of Dicotyledonous Root

To get an idea of the internal structure of a dicotyledonous root, the root of *Dolichos Lablab* may be chosen. (Fig. 174). A transverse section of this root taken through the elongating region will show distinctly two parts, namely a very broad bulky cylinder called the **Primary Cortex** and a central core of tissue, consisting relatively of small cells, called the **Stele**. The cortex will have on it a superficial covering consisting of an unbroken series of thin walled cells or the **Epiblema**. If followed upwards towards the apex the stele will be found to be continuous with the plerome, the cortex with the periblem, and the epiblema with the dermatogen. In the transverse section the cut ends of procambial strands, or those of xylem vessel will be present in the stele. In the longitudinal section the nature of the xylem vessels or the procambial strands can be made out. The xylem vessels are the beginnings of the water conducting channel. As these vessels are surrounded by parenchymatous cells, their cavity may become obliterated and, as a protection against this, inside the thin walls of the vessels, thickenings occur either as isolated rings, or in the form of a continuous spiral. As this part of the root is still growing in length, the successive turns of the spiral or the rings may be pulled apart. So long as these rings or spirals are not separated too widely, they are not likely to be affected by the turgidity of the surrounding parenchyma.

In a section taken through the root hair region of the root the outermost layer consists of a layer of cells many of which are extended outwards as root hairs. Hence this layer is called the **Piliferous Layer**. All the cells of the primary cortex are parenchymatous and they are in close contact with one another, but intercellular spaces are present. The innermost layer of the cortex consisting of cells, different in appearance from those of the cortex is called



the **Endodermis**. It usually consists of rectangular prismatic cells, all continuous and in close contact laterally without intercellular spaces. In the transverse section the radial walls show a dark spot called *Caspary dots* (Fig. 173). These dots are the cut ends of a thickened band of cutin running all round each cell, along its radial and transverse walls. The inner and the outer tangential walls of the cells of the endodermis are thin and of cellulose. The endodermis on account of these bands and the general shape of its cells sharply marks the limit between the cortex and the stele. In dicotyledonous roots the endodermis possesses these characteristics only for a short time, but afterwards it becomes indistinct. But in monocotyledonous roots this layer persists and the cells become thickened laterally and internally.

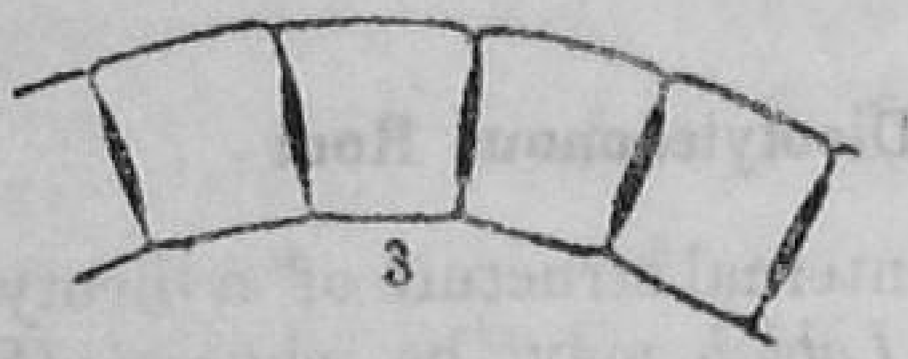


Fig. 173. Endodermal calls showing the caspary dots and the bands. (1) a single cell of the endodermis (2) transverse section of endodermal cells.

The outermost layer of cells of the stele abutting on the endodermis forms the **Pericycle**. In roots the pericycle consists always of a single layer of cells. The most prominent tissues in the stele are the four distinct groups of thick walled cells lying at equal distances from one another, called the **xylem strands** or bundles. These xyelm bundles abut on the pericycle and the vessels with small cavities close to it are the first formed vessels and consist of annular and spiral vessels. These are first formed xylem vessels and are called **Protoxylem** (protos=first formed). The vessels of the xylem bundles get larger and larger from the periphery to the centre of the stele. These internal vessels with widest lumen are formed later and usually consist of reticulated and pitted vessels. In contrast to the protoxylem these vessels with wider lumen are designated **Metaxylem**. Thus it is obvious that annular, spiral, reticulated and pitted vessels follow in order from without inwards. In other words, the development of the vascular bundle in the primary root is **Centripetal**. (Fig. 174, 175).

Alternating with these we find four phloem strands. These together with the xyelm bundles constitute the vascular bundles. The xylem and the phloem bundles lie side by side laterally on distinct radii and hence they are said to be **Radial**.

The phloem strands are distinct only in somewhat older sections passing through the root hair region, because along with the

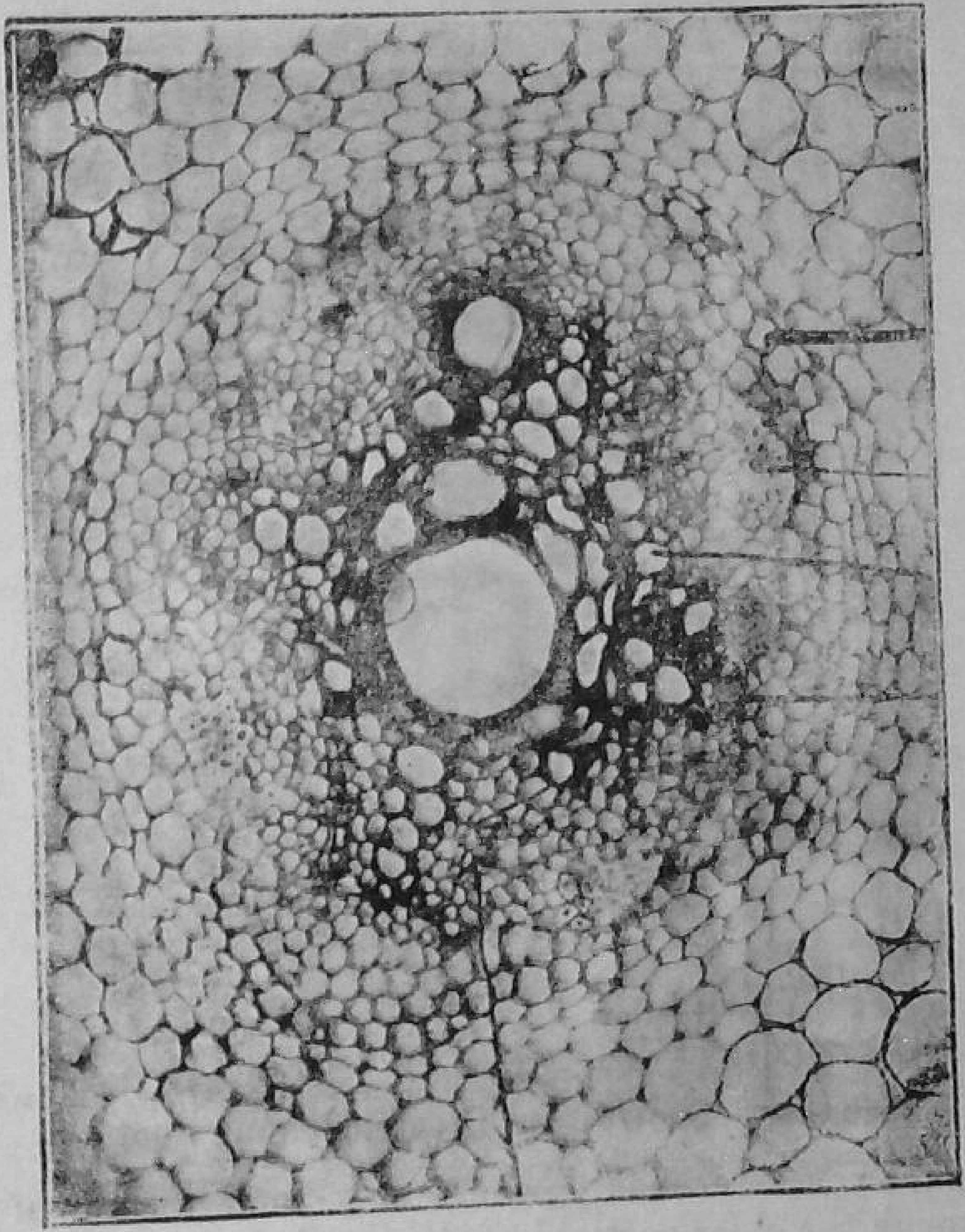


Fig. 174. Transverse section of the root of *Dolichos lablab* taken through the root hair region. (1) endodermis (2) sclerenchyma (3) secondary xylem (4) cambium (5) primary xylem.

sieve tubes and the parenchyma cementing them, sclerenchymatous fibres appear. In roots younger than this the phloem strands are not strongly developed and so they cannot be distinguished easily from the surrounding conjunctive parenchyma. The phloem consists mainly of sieve tubes cemented together by phloem parenchyma. In somewhat older roots sclerenchyma fibres are formed externally to the phloém strand so as to protect the sieve tubes feom being obliterated by the turgidity of the parenchyma adjoining them.

In the primary root the spaces between the vascular bundles and the pericycle are filled up by parenchyma. The four xylem bundles grow towards the centre of the stele and consequently

they all meet in the centre. Thus all the lignified tissues become closely united into a mechanical central resistent cord so essential for the root, to withstand the longitudinal tension.

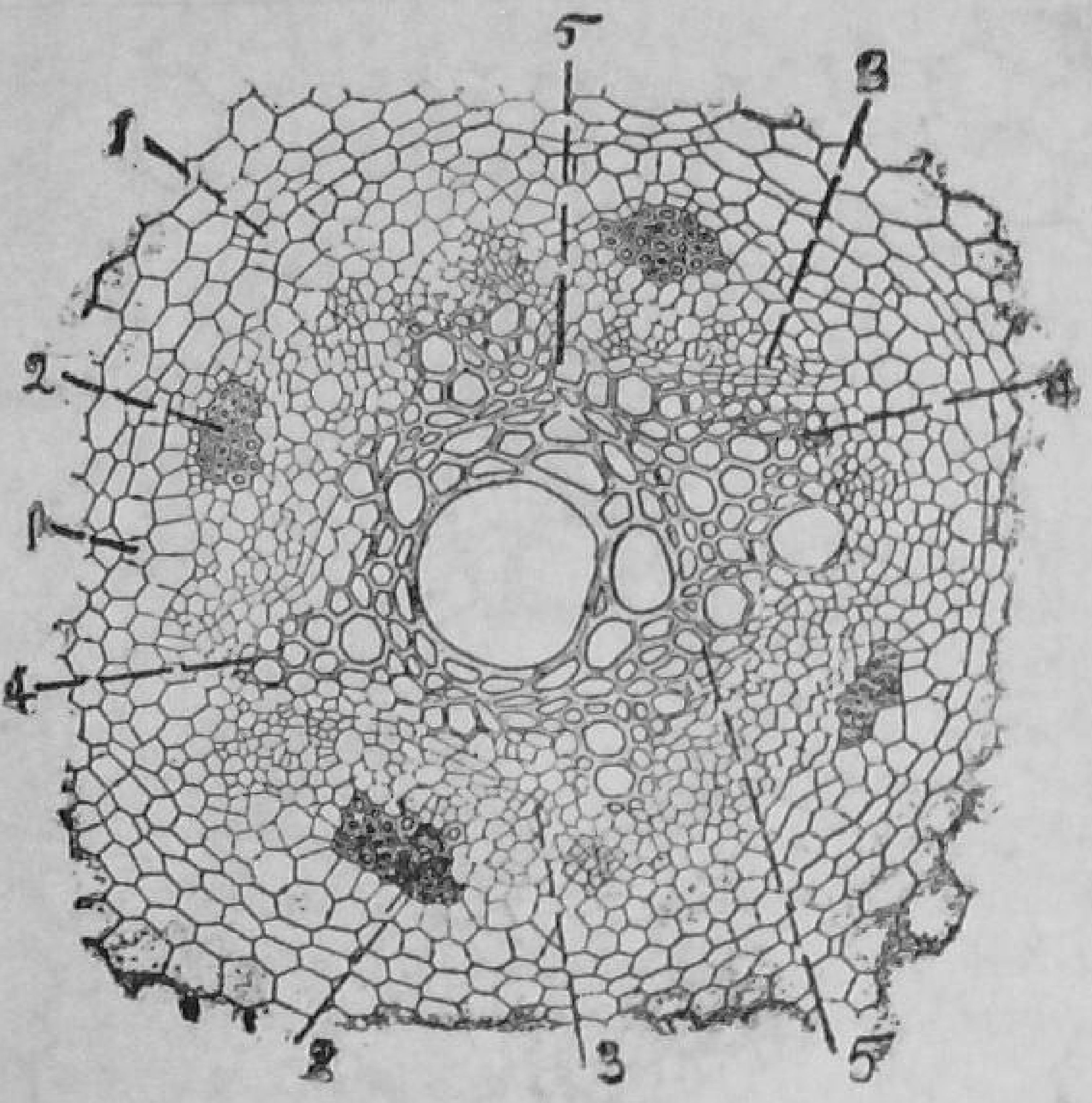


Fig. 175. Transverse section of the root of *Dolichos lablab* (1) endodermis (2) Sclerenchyma (3) Cabium (4) Primary xylem (5) Secondary xylem.

Secondary Growth in Dicotyledonous root

Formation of secondary cambium.—In sections of roots taken through the older portions of the root-hair region or younger portions of the conducting region, the differentiation of the tissues will be very marked and in general there will be an increase in xylem elements. In such a section all the four primary xylem bundles would be found welded together by the formation of xylem elements in the centre. Further, in the parenchyma lying between the xylem and phloem, cell divisions appear. By this activity arcs of cambial tissue are formed internally to the phloem. Then the pericycle lying next to the protoxylem begins to divide and with the cambium already formed, a cylinder of cambium is formed.

Formations of secondary bundles.—This cambium produces parenchymatous cells both inside towards the xylem and outside towards the phloem. The parenchymatous cells arising at the back of the four primary xylem groups appear as four broad medullary rays. Such of the parenchymatous cells as are close to the phloem become part of the phloem changing into sieve

tubes or remaining as phloem parenchyma. These cells which abut on the xylem get gradually changed into xylem elements.

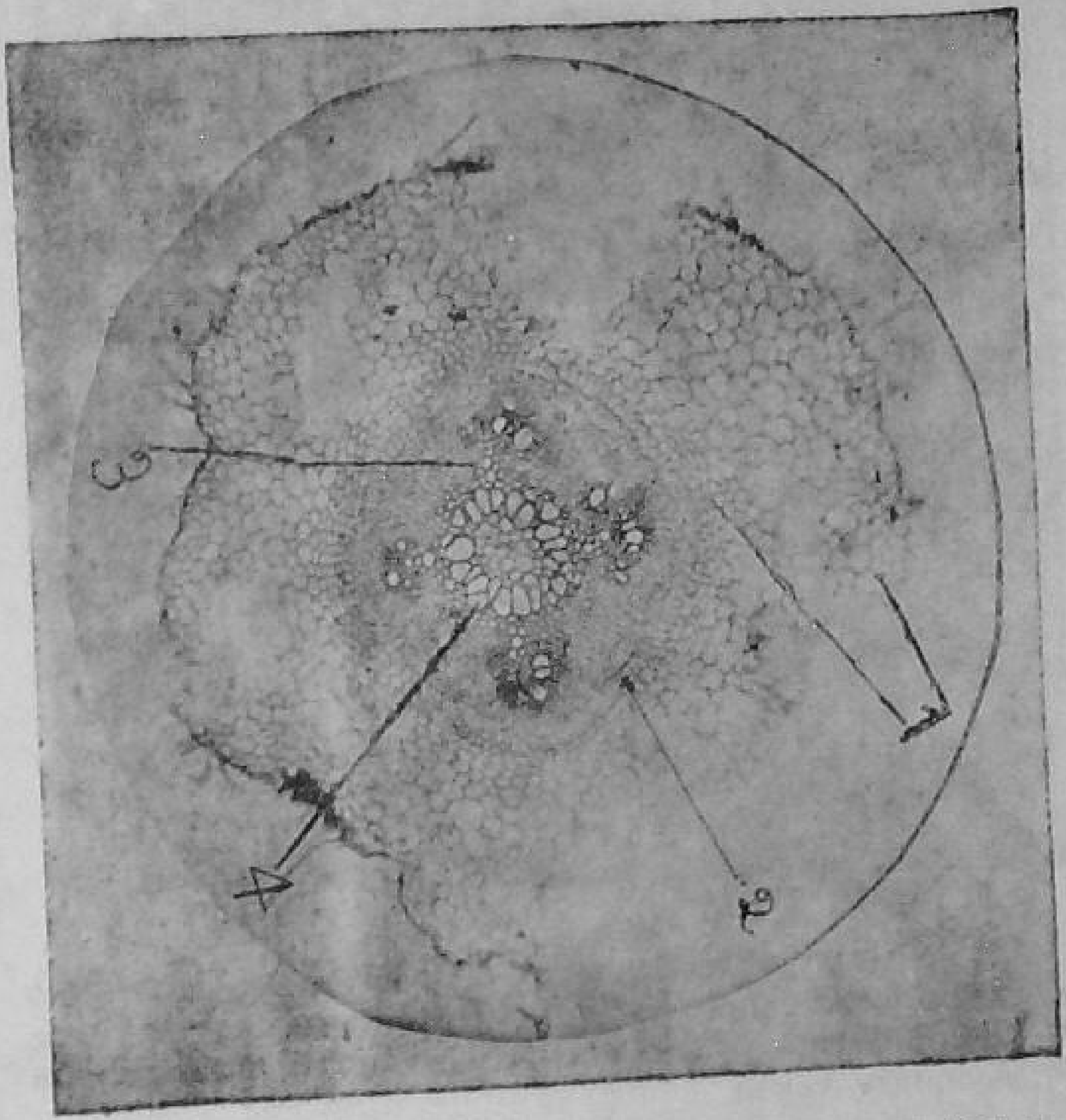


Fig. 176. Transverse section of an old root of *Dolichos lablab* (1) Cortex (2) Cork tissue (3) Primary xylem (4) Secondary xylem.

Formation of cork.—Simultaneously with these changes, the parenchyma of the cortex undergoes changes. The parenchymatous cells lose their protoplasm and become filled with air. As soon as the cells of the cortex become dead, they gradually peel off and protection is afforded by the **Secondary Cortex** formed of cork tissue. (Fig. 176, 177).

Formation of cork tissue by the activity of the pericycle begins in the root of *Dolichos Lablab* long before the stripping off of the dead cortex cells. Soon after the cambium ring is well established, the pericycle begins to divide all round and forms cork tissue and, consequently cortical cells die and gradually the cortex wears out, and its place is taken by the cork whose development is continued by cork cambium. So a transverse section of an old root is devoid of the primary cortex and the stele only persists and the protective tissue cork is formed from the pericycle. An old dicotyledonous root acquires a structure very similar to that of an old stem on account of the activity of the cambium ring. It is distinguished rom the stem by the presence of primary xylem and phloem trands at the centre.

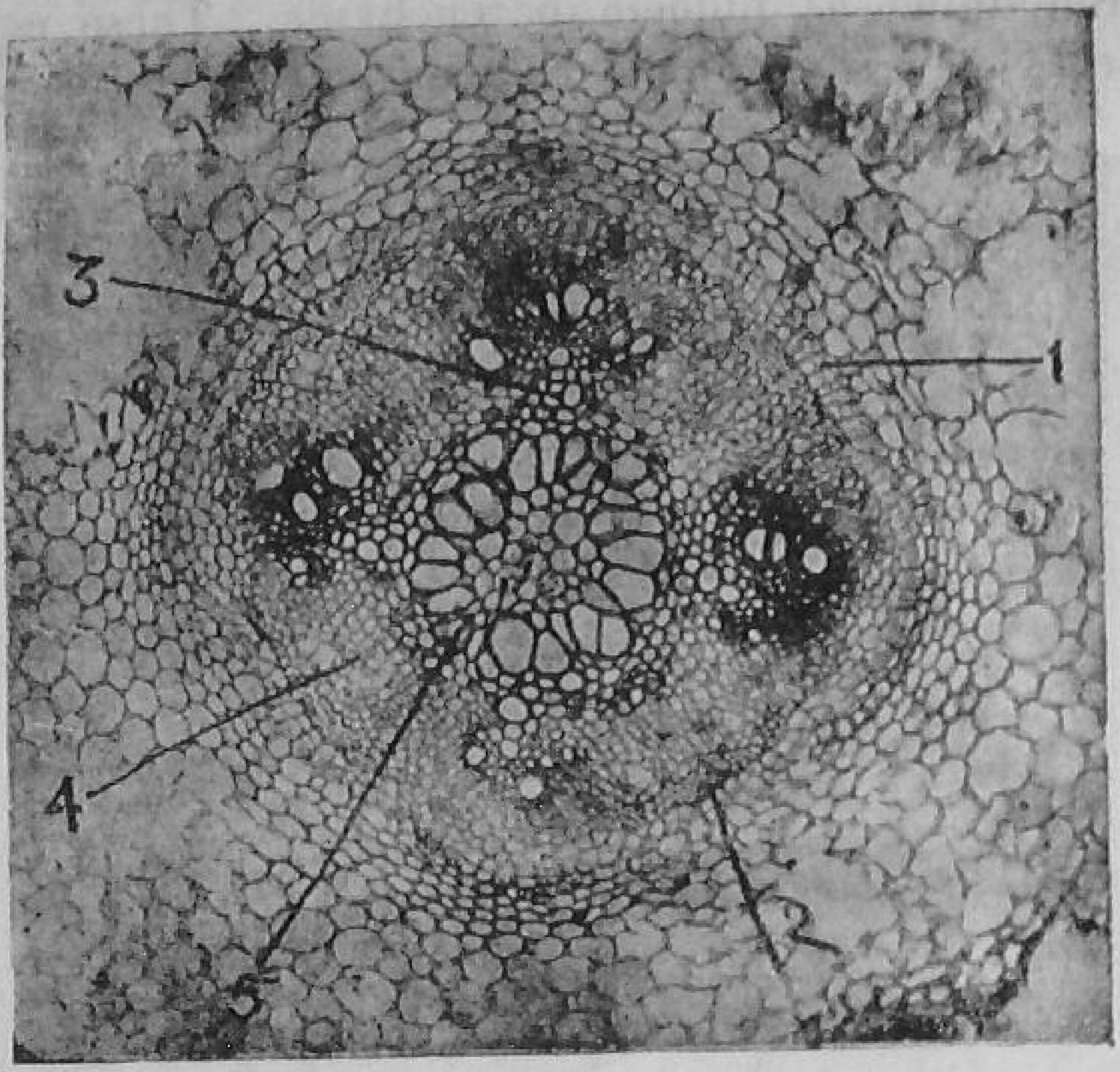


Fig. 177. Transverse section of an old root of *Dolichos lablab* showing the stele and a portion of the cortex (1) cork tissue (2) sclerenchyma (3) primary xylem (4) cambium (5) secondary xylem.

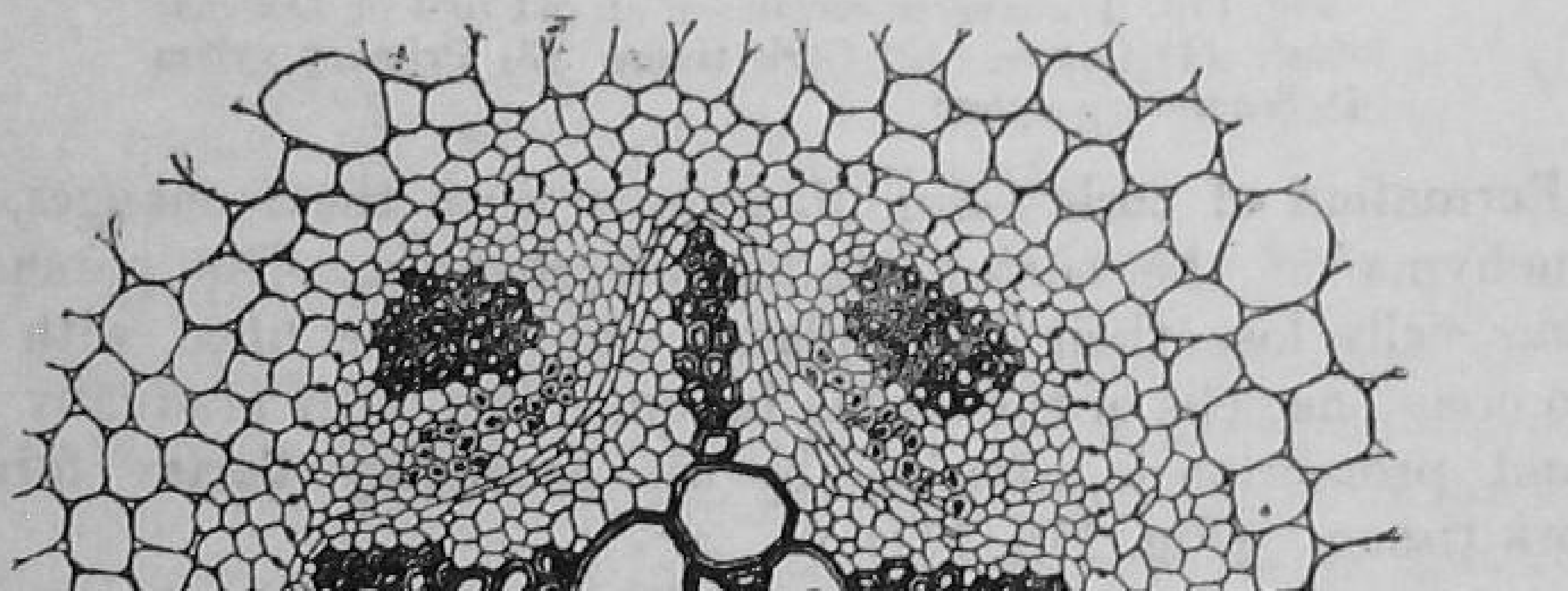
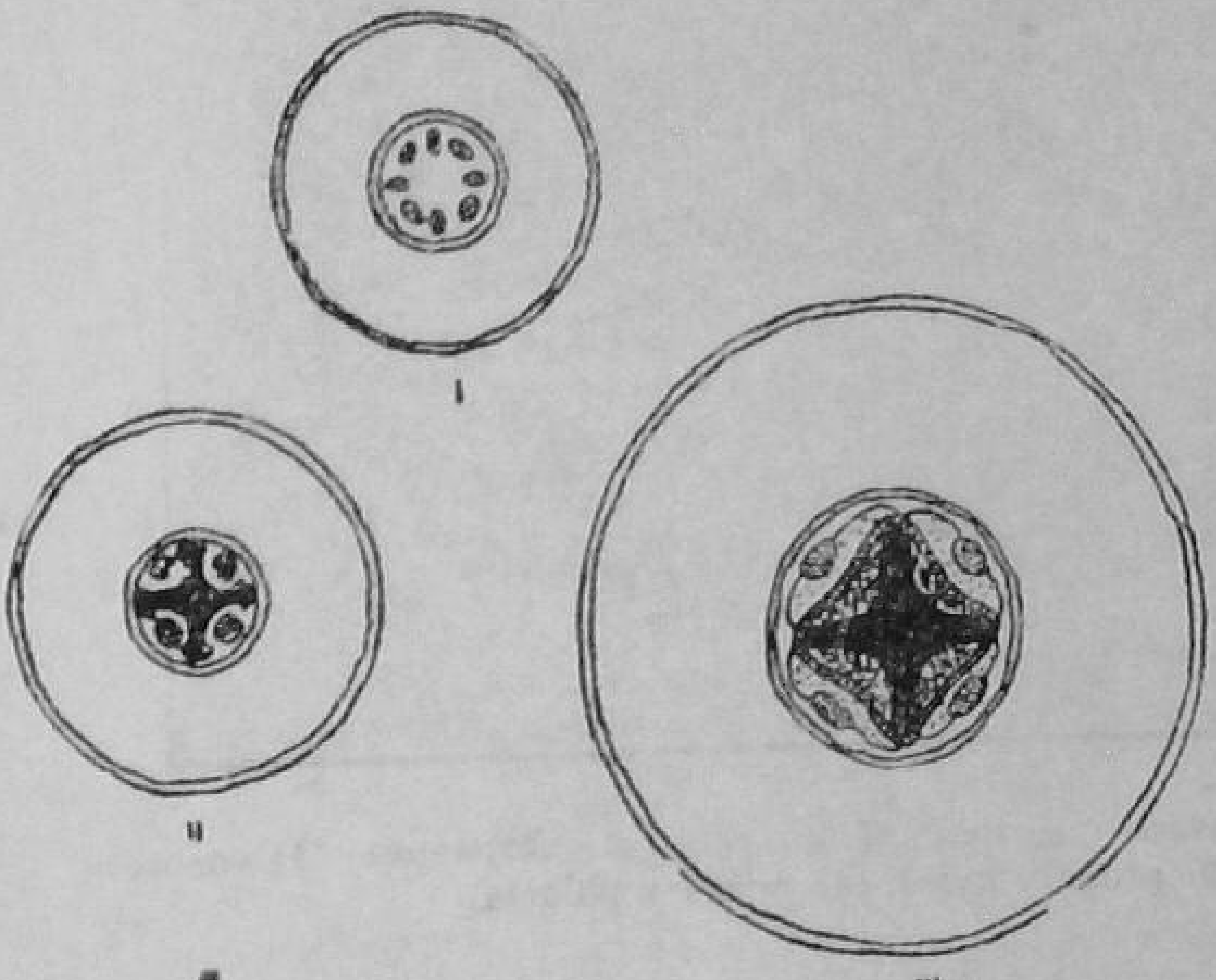


Fig. 178. Secondary thickening in a dicot root. End-Endodermis; S.P. secondary phloem; P.P. prionary phloem; P.X. proto-xylem; M.X. meta-xylem.

In all essential features the roots of dicotyledonous plants resemble the roots of *Dolichos Lablab* so far as their internal structure is concerned (Figs. 178, 179 & 180). But, however, dicotyledonous roots vary in the number of primary xylem strands. They may be two as in the roots of *Raphanus* (Fig. 181) and *Brassica*, three as in the roots of plants of the family composital; four as in the roots of *Benincasa cerifera* (Fig. 182) and leguminous plants: or five or six as in the roots of *Ricinus communis*.



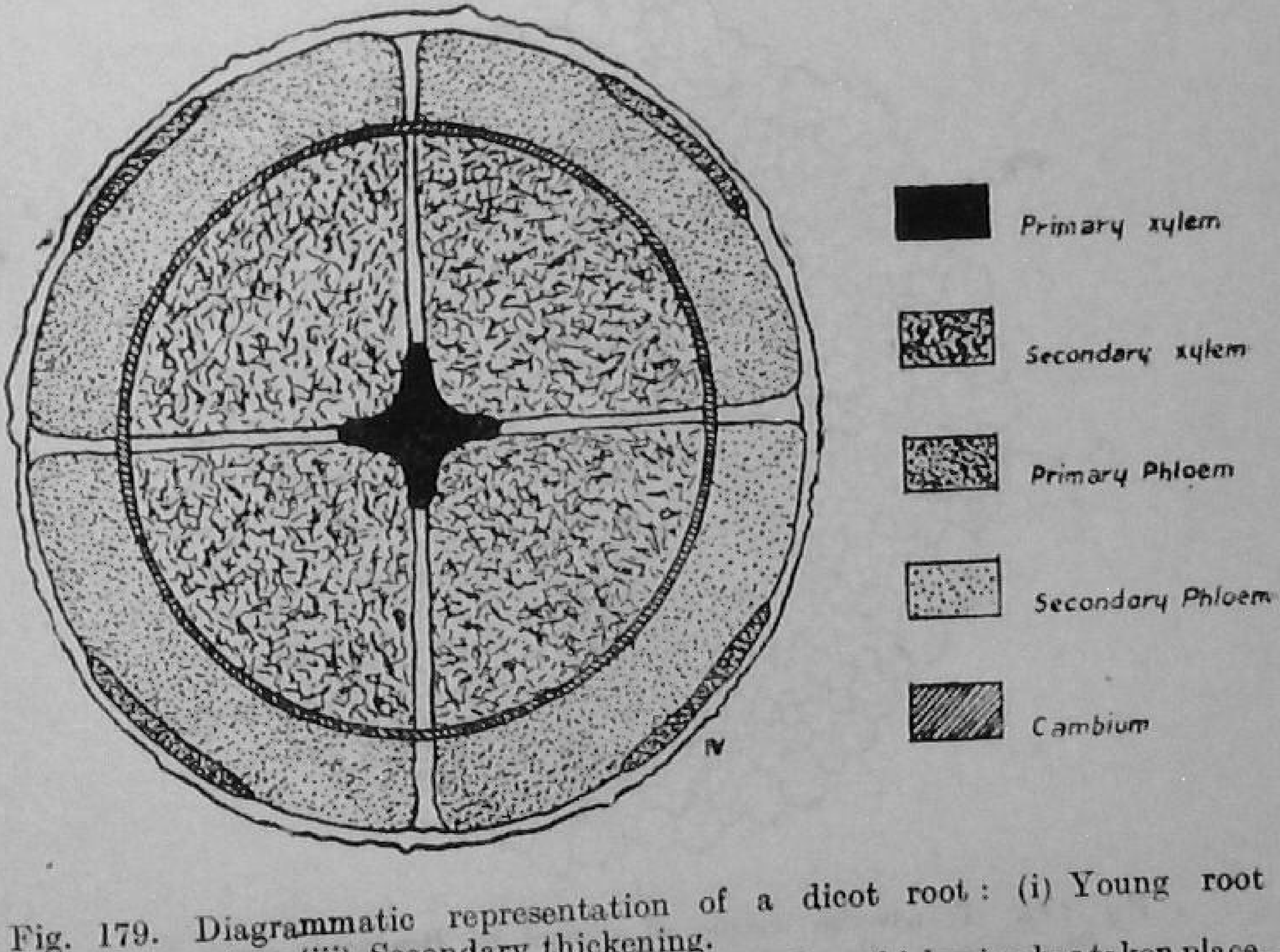


Fig. 179. Diagrammatic representation of a dicot root: (i) Young root (ii) Older stage (iii) Secondary thickening.
Fig. 180. An old dicotyledonous root in which secondary thickening has taken place.

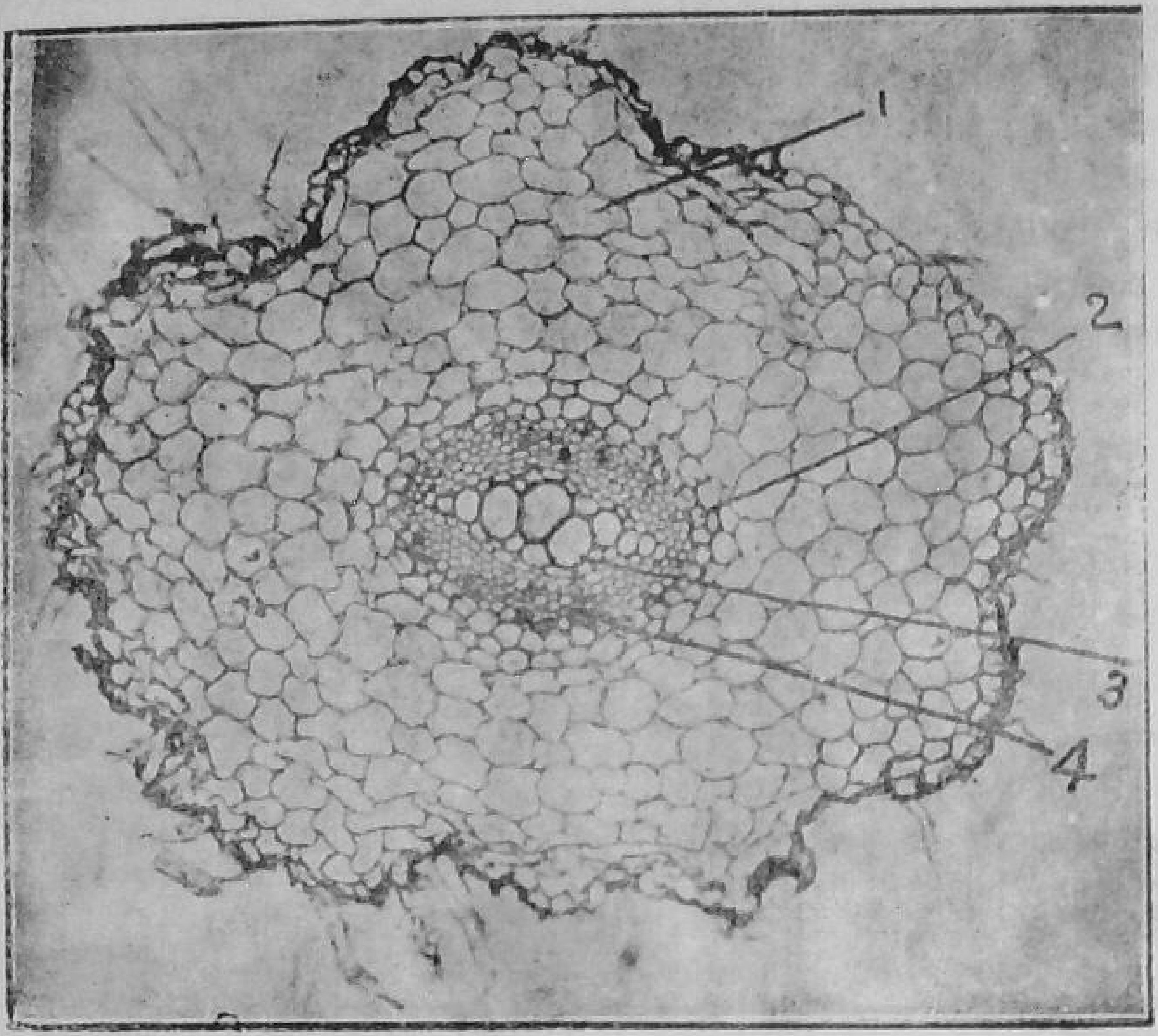


Fig. 181. Transverse section of a root of *Raphanus* (1) cortex (2) pericycle (3) primary xylem (4) primary phloem.

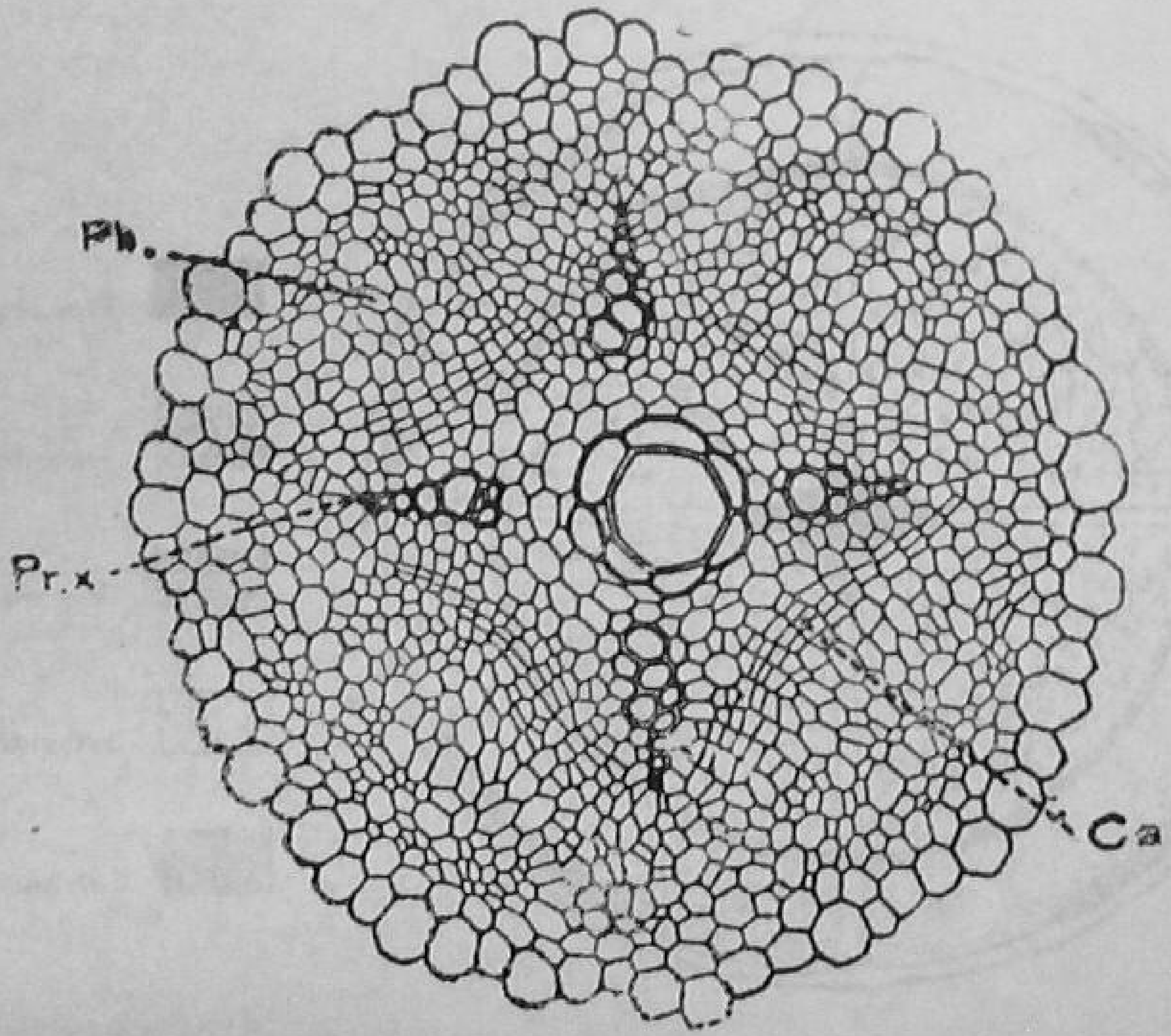


Fig. 182. Transverse section of a root of *Benincasa cerifera* Ph=phloem ; Pr. x=Primary xylem ; Ca=Cambium.

Monocotyledonous Roots.

As an example of monocotyledonous root we may study the root of onion. In a transverse section of the onion root a

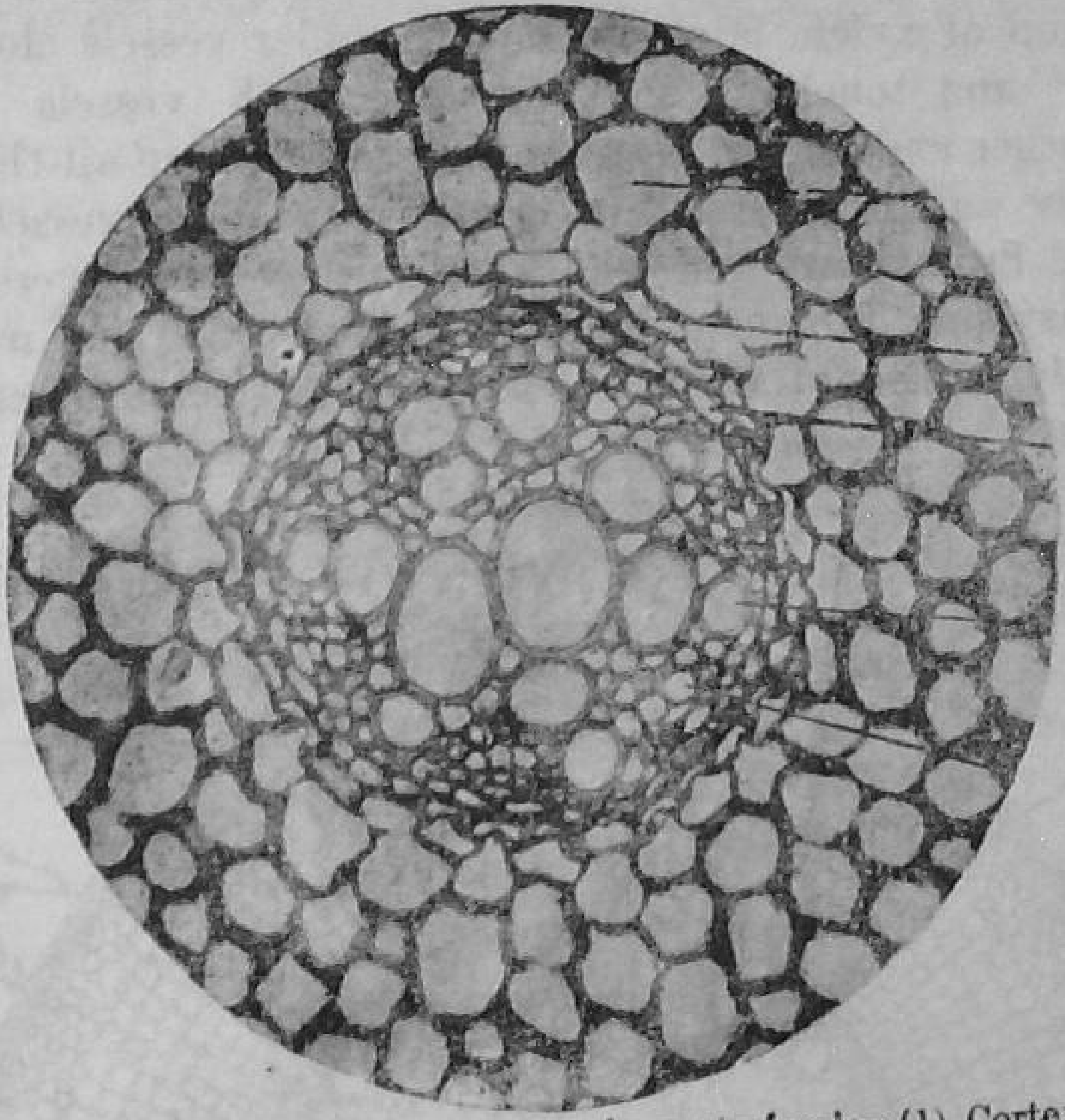


Fig. 183. Transverse section of a root of onion (1) Cortex (2) endodermis (3) pericycle (4) protoxylem (5) phloem.

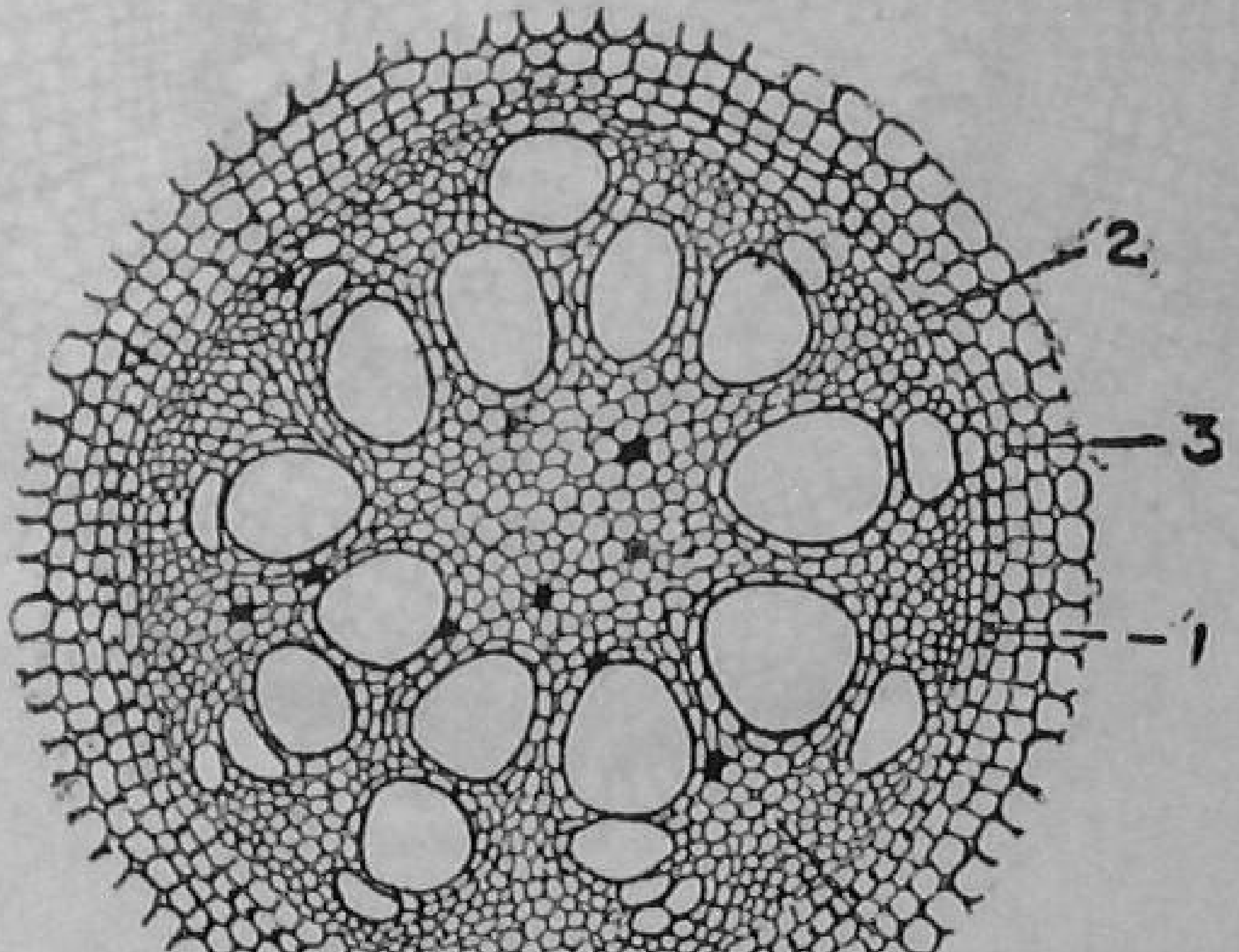


Fig. 184. Transverse seccion of a root of *Colocasia* showing the stele (1) endodermis (2) pericycle (3) protoxylem (4) phloem.

broad cortex is seen to surround the stele. The endodermis is well marked. Within the stele are present (1), pericycle and (2) seven groups of xylem vessels. Alternating with these seven primary xylem groups there are (3) seven groups of phloem. Each group of xylem is composed of smaller vessels close to the periphery and touching the pericycle, with vessels in front getting larger and larger towards the centre where all the groups meet. The smaller vessels are annular and spiral vessels constituting the **Protoxylem**, and the later formed pitted vessels form the **Metaxylem**. No cambium is formed. **So the monocotyledonous type of root maintains its primary structural conditions throughout.**

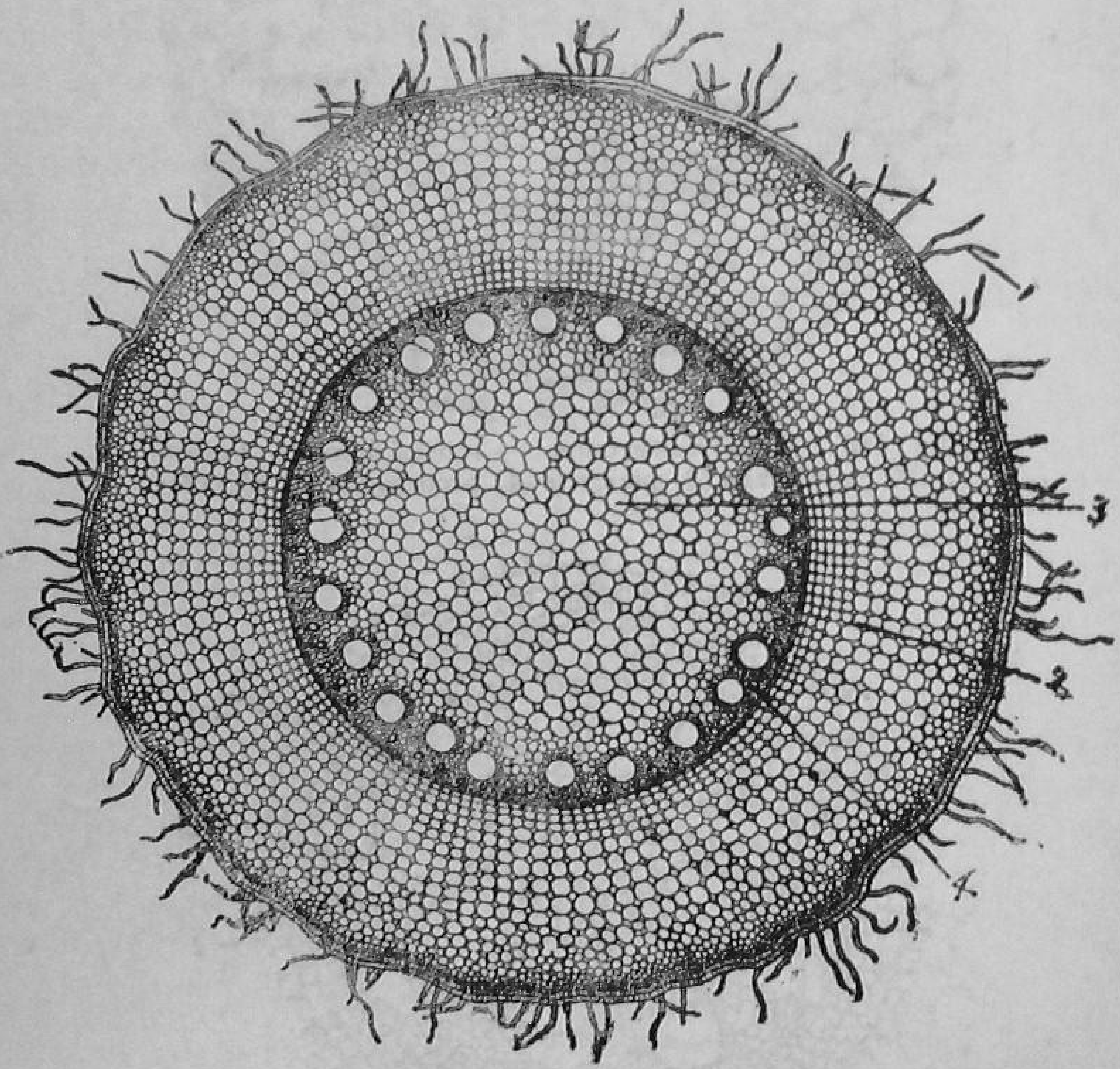


Fig. 185. Transverse section of the root of Sorghum (1) root hair (2) cortex (3) pith (4) protoxylem groups.

In transverse sections of *Colocasia* root there will be nine to eleven primary xylem groups (Fig. 184). The endodermis is well

marked and the cortex is broad consisting of parenchyma with intercellular spaces.

As further examples of monocotyledonous type of root, we may examine the roots of *Sorghum*, *Cenchrus ciliaris* and *Musa Paradisiaca*.

In a transverse section of the root of *Sorghum* we find a fairly broad cortex surrounding the stele. (FIG. 185). The inequality between the cortex and the stele is not so great as in the onion (Fig. 183) or *Colocasia* root. Outside the cortex there is a distinct piliferous layer. Besides the formation of the internal endodermis, in the monocotyledonous roots, the cortex forms externally a layer called **Exodermis**, just below the piliferous layer. (Fig. 186). The cells of the exodermis fit close together without intercellular space and their walls become suberised. Although it may consist of one layer when young, it is usually several layered. It is a living physiological barrier. The exodermis is broken here

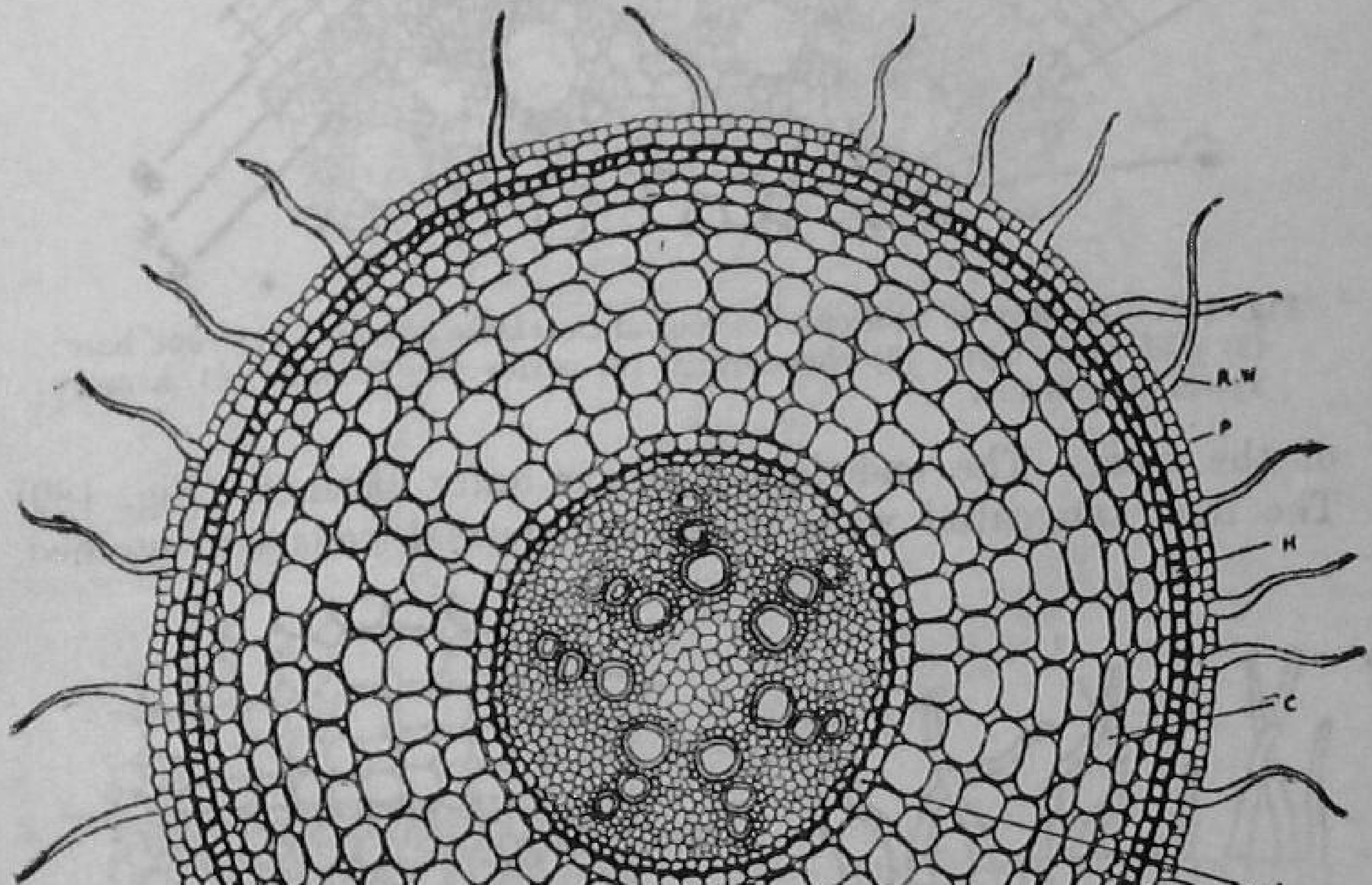


Fig. 186. Transverse section of a root of a grass. R.H.=root hair P=piliferous layer; E=Exodermis; C=Cortex; End=Endodermis.

and there by living parenchyma called **Transfusion Cells**, through which translocation of food materials is effected. In roots that are aerial the exodermis is very well developed (Fig. 188) and the reason for this will become obvious after the study of the structure

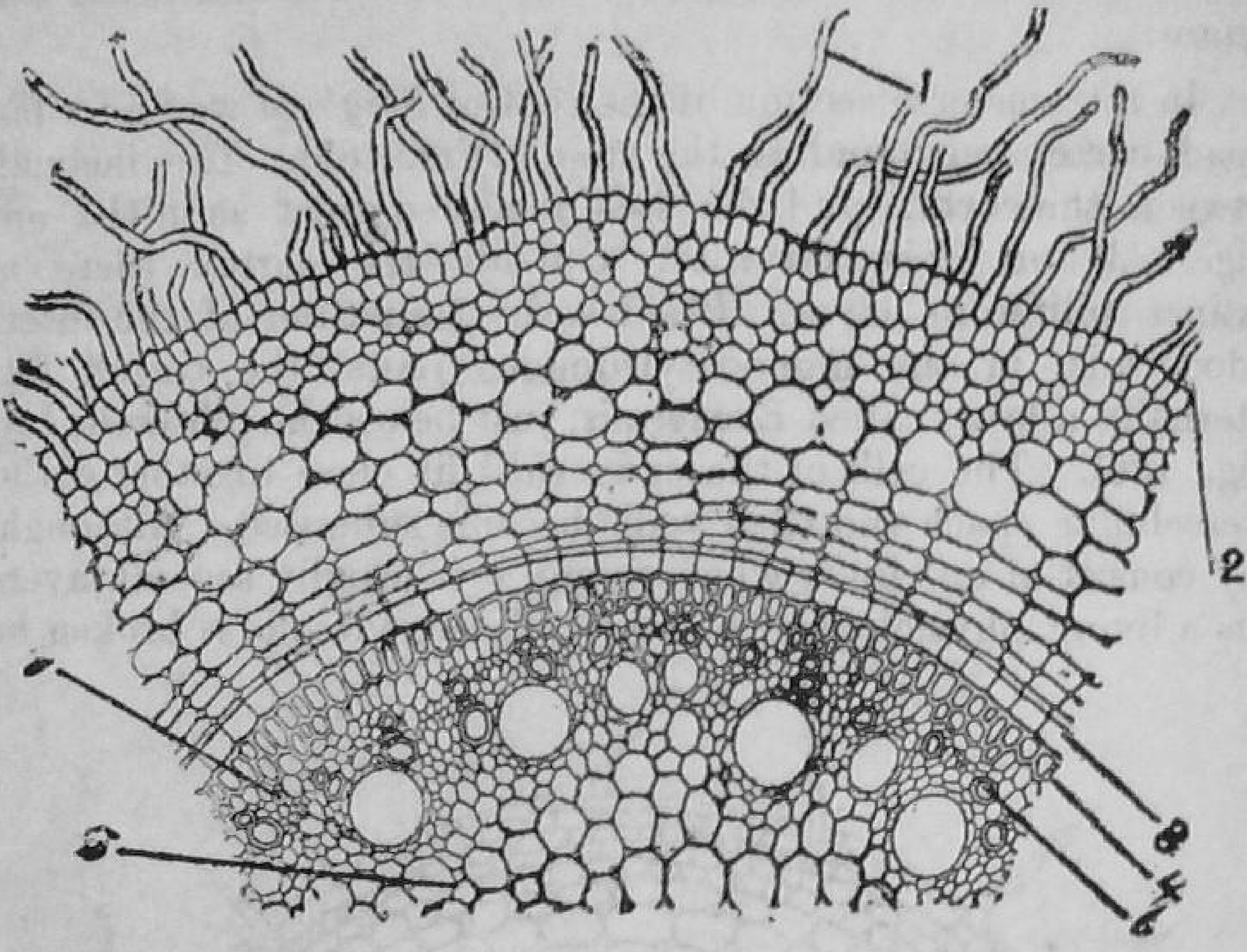


Fig. 187. Transverse section of a root of *Cenchrus ciliaris*; (1) root hair; (2) piliferous layer (3) endodermis (4) pericycle (5) pith (6) primary xylem (7) phloem.

of the stem. The endodermis also is quite distinct. (Fig. 189) The inner tangential walls of the endodermal cells are lignified.

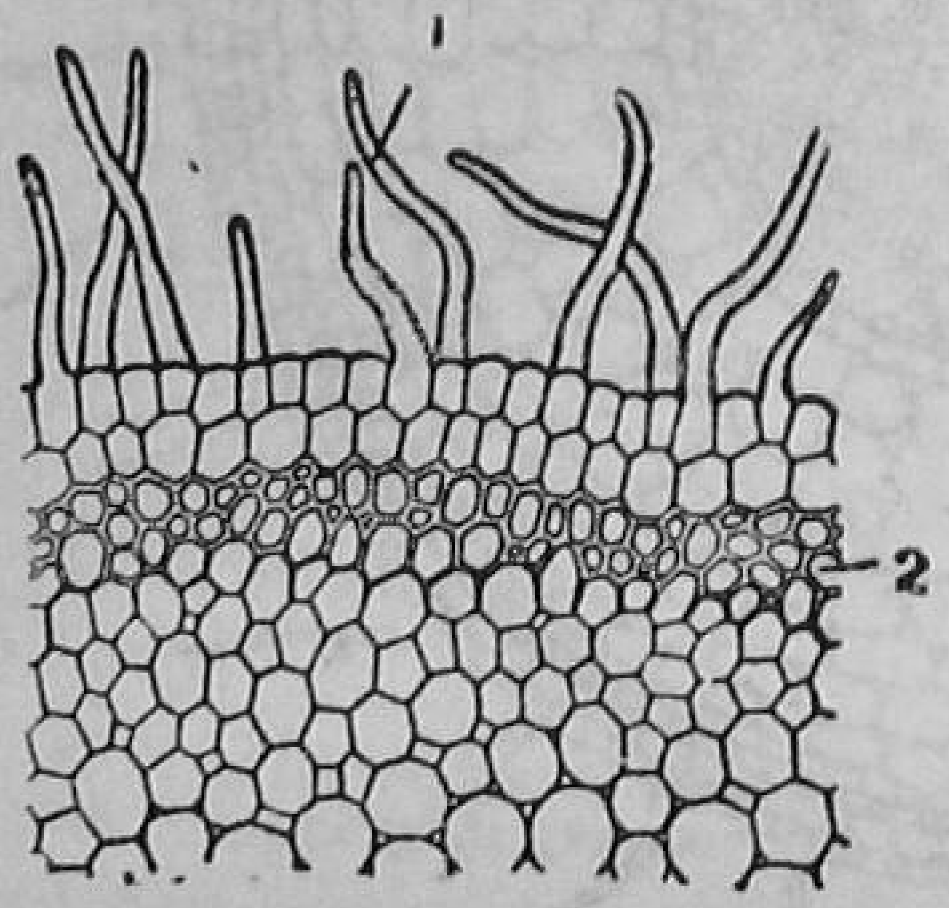


Fig. 188. Transverse section of a portion of the cortex of a root with piliferous layer of *Sorghum* (1) root hair (2) exodermis.

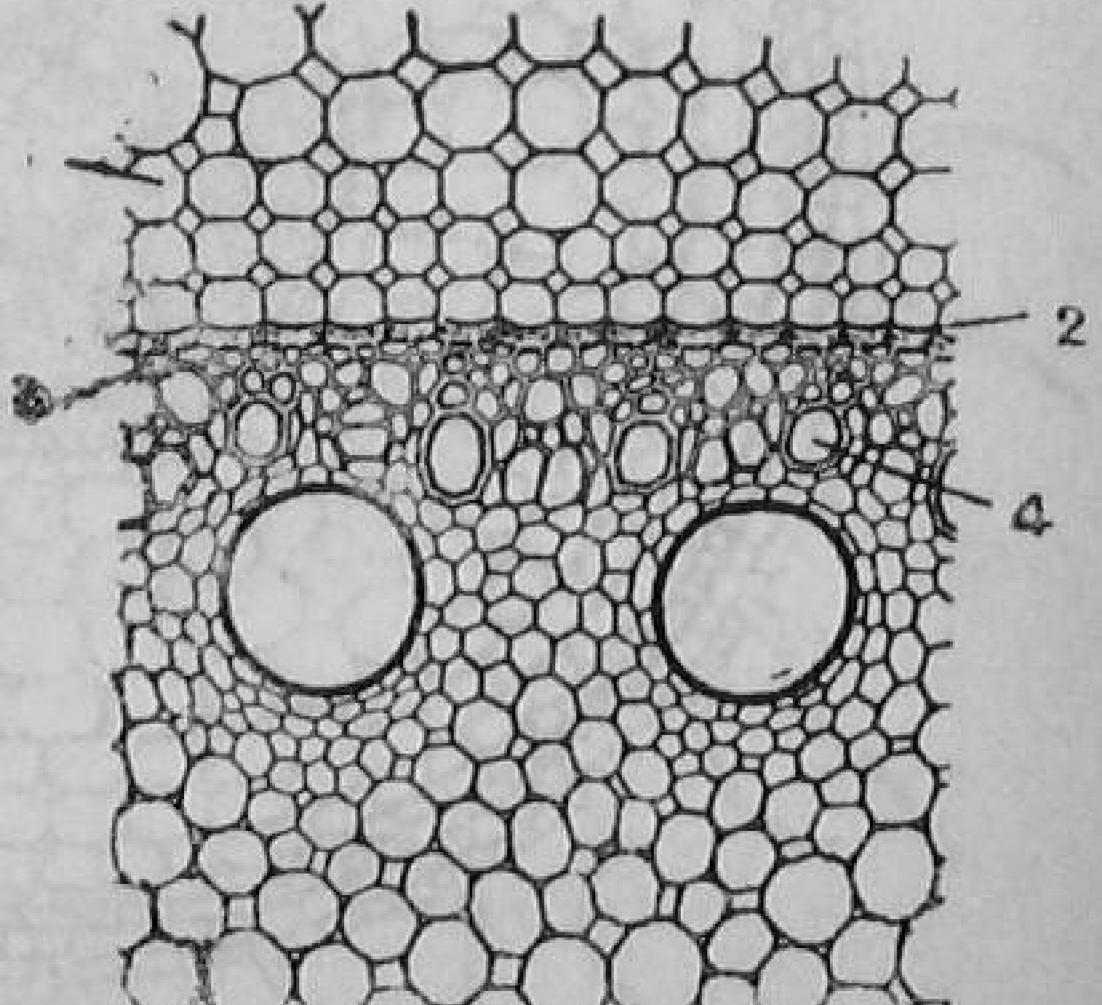


Fig. 189. Transverse section of a portion of the stele of the root of *Sorghum* (1) cortex (2) endodermis (3) pericycle (4) protoxylem.

Within the stele there are a large number of primary xylem groups and as many phloem groups also. The major portion of the stele in the centre consists of parenchyma. When the root gets older the cell walls of the pericycle and of the parenchymatous cells in the centre become thickened so that the lignified tissues are all welded together into a central mechanically resistant strand.

The structure of the root of *Cenchrus ciliaris* in transverse section is shown in Fig. 187. The general structure and arrangement of tissue is practically similar to that of the root of Sorghum. But the stele is larger and the cortex is comparatively narrower.

The root of *Musa paradisiaca*, though conforming to the general monocotyledonous type of structure, presents certain special features (Fig. 190).

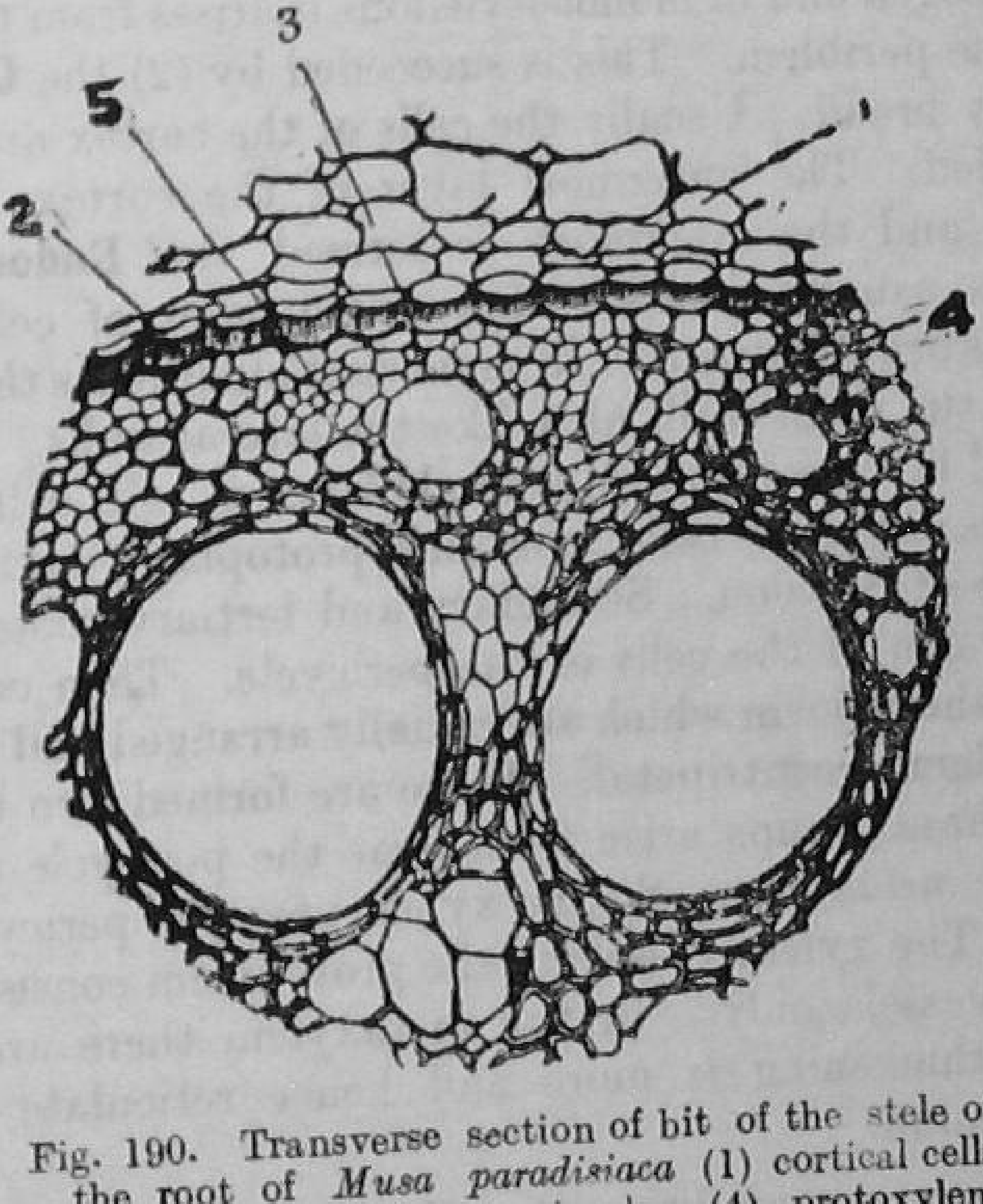


Fig. 190. Transverse section of bit of the stele of the root of *Musa paradisiaca* (1) cortical cells (2) endodermis (3) pericycle (4) protoxylem (5) secondary phloem.

The layer of endodermis is a very striking layer on account of the great thickening of the inner wall of its cells. Next to this lies the pericycle as a single layer of cells.

Within the stele there are more than thirty groups of primary xylem alternating with as many groups of phloem, and all these are at the periphery of the stele abutting on the pericycle. The central portion of the stele is occupied by numerous xylem vessels, and there are also phloem groups irregularly disposed amidst the

xylem. The cortex presents no special features, except the very regular arrangement of the cells with uniform intercellular spaces. Another marked feature is the lignification of the walls of all the cells within the stele, except the elements of the phloem. The exodermis is not so well developed in this root.

Briefly considered, in the primary condition of a *dicotyledonous root* we find the following in transverse section, (1) externally the **Epiblema** or the **Piliferous** layer, consisting of a layer of cells and bearing root hairs here and there. The main work of this part of the root is to absorb the water from the soil. When root hairs arise from cells as protuberances then the layer is termed **Piliferous** and when the cells are without root hairs they are termed **Epiblema**. In dicotyledons, the epiblema is formed from the dermatogen and in monocotyledons it arises from the outermost layer of the periblem. This is succeeded by (2) the **Cortex** which is generally broad. Usually the cells of the cortex are thin walled and rounded. The outermost layer of the cortex is called the **Exodermis** and the innermost is termed the **Endodermis**. The endodermis usually consists of a single layer of cells and their radial walls are thickened. In somewhat older roots the thickening extends to the inner walls also, like the lateral walls. Next to the endodermal layer we find (3) a single layer of cells called the **Pericycle**. This layer of cells contains protoplasm and these cells are capable of division. Secondary and tertiary roots are formed by the division of the cells of the pericycle. Then comes (4) the xylem and the phloem which are radially arranged and the development of xylem is centripetal. There are formed two to six xylem groups. These groups arise from near the pericycle and proceed towards the *metaxylem*. So the xylem near the pericycle is called *protoxylem*. The xylem vessels in the protoxylem consist of annular and spiral vessels only. In the metaxylem there are vessels in which the thickening is more and hence reticulate and pitted vessels are found.

In the primary condition there is much resemblance in structure between the monocotyledonous and dicotyledonous roots. But the monocotyledonous roots have a broader pith than the dicotyledonous roots and the number of xylem groups are more numerous in the monocotyledons than in the dicotyledons.

Formation of lateral roots.—Lateral roots originate from the deeply seated pericycle and force their way through the cortex of the parent root. So in the case of roots the pericycle is a very important layer in both monocotyledons and dicotyledons. Every lateral root springs from the pericycle usually at a point close to

one of the protoxylem groups. In dicotyledonous roots, there will be as many longitudinal rows of lateral roots as there are protoxylem groups. For instance, we see in the tap root of *Dolichos* seedling four longitudinal rows of lateral roots, and the protoxylem groups are usually four in this root. The roots of *Raphanus* and *Brassica* have only two protoxylem groups and, therefore, we find in these roots only two rows of lateral roots.

CHAPTER XIV

INTERNAL STRUCTURE OF STEM

Although the structure of stems varies with the species of plants and the stage of development in the same plant the arrangement and distribution of tissues are more or less alike, in all essential respects, in the primary condition of the stem of the different plants. The stem is generally soft and herbaceous in annuals and in the younger parts of shrubs and trees. The older parts of shrubs and trees are hard and woody.

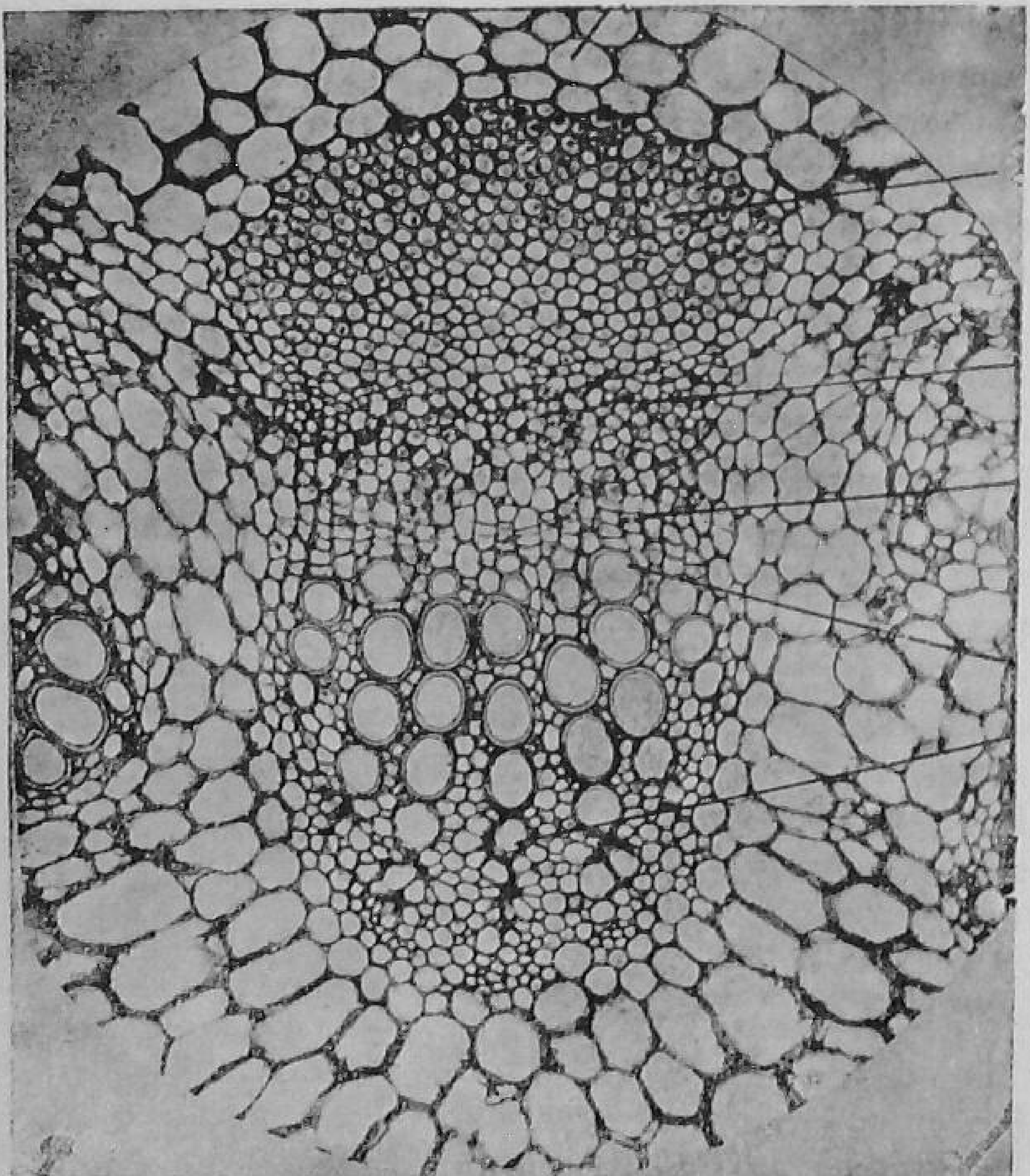


Fig. 191.—Transverse section of a single vascular bundle inth stem of *Helianthus annuus*. (1) Cortex, (2) sclerenchyma. (3) phloem, (4) cambium, (5) xylem.

The structure of the growing point of the stem is the same in all angiospermous plants, so far as the essential features are

concerned. It consists of a mass of meristematic cells terminating in a cone and covered by the developing young leaves. Axillary branches arise very early as protuberances in the axils of leaves near the actual growing point. They remain dormant for a long time. It is the leaf that grows rapidly one after the other, while the axis does so very slowly. In consequence of this difference in growth between the axis and appendages, the young leaves developing near the growing point cover and protect it.

To get an exact idea of the internal structure of stems of plants it is necessary to select as types a few plants, and study the tissues and their arrangement in transverse and longitudinal sections of the stems of plants so selected (Fig. 192). We shall take as types

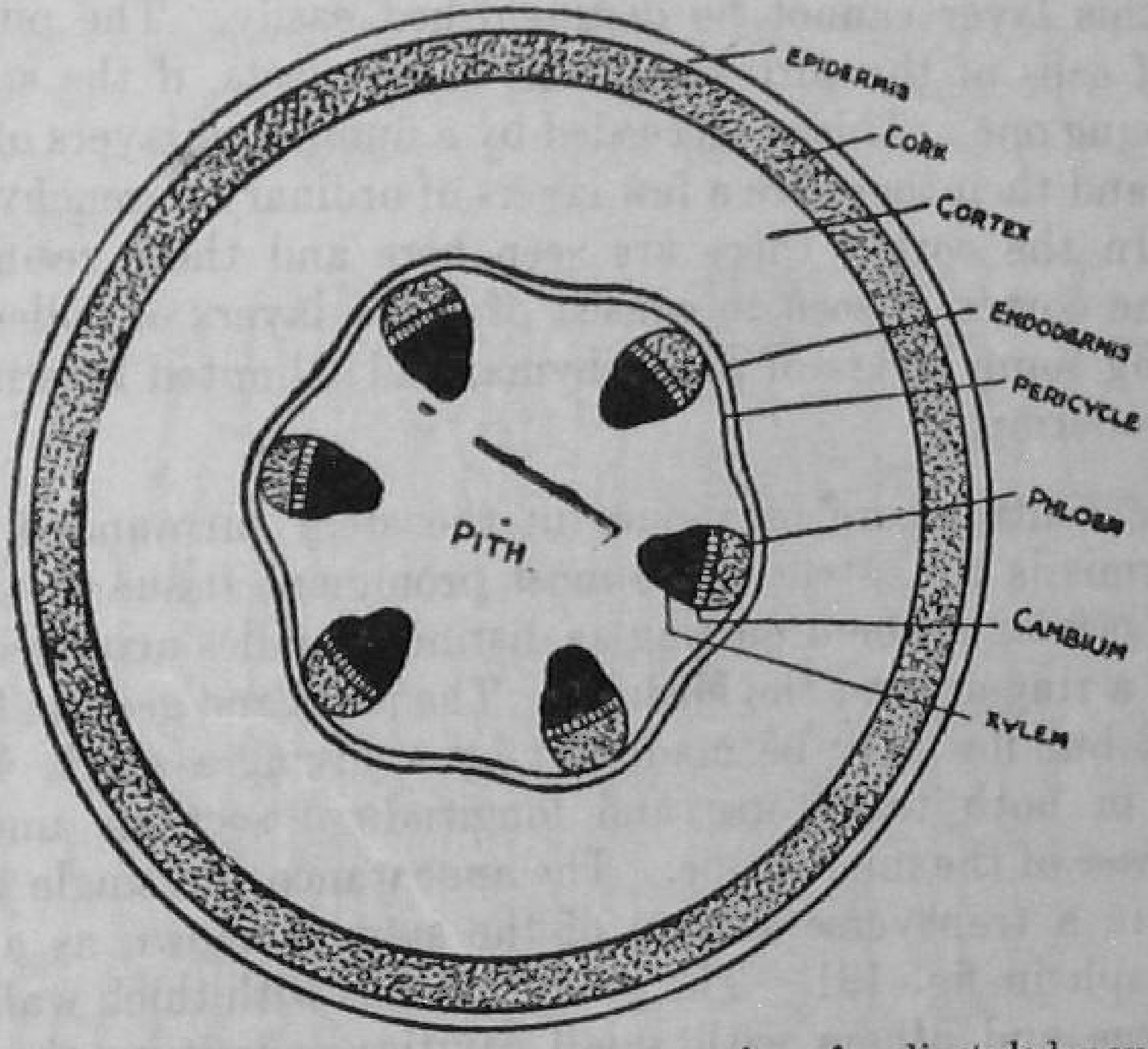


Fig. 192. Diagrammatic transverse section of a dicotyledonous stem.

the stem of the plants, *Helianthus annuus*, *Hibiscus cannabinus*, *Aristolochia bracteata*, *Cucurbita maxima* and *Thespesia populnea* for dictoyledons.

Dicotyledonous Stem

Primary Structure.—A transverse section of the stem of *Helianthus annuus*, (Fig. 191) taken an inch or two below he growing point, consists of a number of isolated vascular bundles

arranged in the form of a ring enclosing a large area of **Medulla** *or* **Pith** in the centre, and separating it form a narrow region of cortex at the periphery. Both the cortex and the pith consist of living parenchymatous cells with numerous intercellular spaces. The vascular bundles themselves are separated one from the other by broad bands of parenchyma uniting the medulla with the cortex. These bands of parenchyma are the **Medullary Rays.**

The superficial boundary layer or the epidermis is a single layer of living cells, each with its lining of protoplasm. The outer wall of each of these cells is thickened and there is also a very thin layer of cutin. Beneath the epidermis lies the cortex consisting of several layers of cells. The innermost layer of the cortex consists of cells containing starch grains and this is the endodermis. Although this layer delimits the stele from cortex in young stems, in older stems this layer cannot be distinguished easily. The outermost layer of cells of the cortex contains chloroplasts, if the stem is a very young one. This is succeeded by a number of layers of collenchyma and then there are a few layers of ordinary parenchymatous cells. In the cortex there are seen here and there resin ducts. Thus the cortex is seen to consist of a few layers of collenchyma overlying some layers of parenchyma, and delimited internally by the endodermis.

The central core of tissues in the stem surrounded by the endodermis is the stele. The most prominent tissue in the stele is the vascular tissue occurring as distinct bundles arranged in the form of a ring around the **Medulla**. The parts and general features of these bundles may be made out by studying a single vascular bundle in both transverse and longitudinal sections under the high power of the microscope. The appearance of a single vascular bundle in a transverse section of the stem is shown as a photomicrograph in fig. 191. The groups of cells with thick walls, some with large and others with small cavities, constitute the **Xylem** portion of the vascular bundle. The larger cavities bounded by thick walls and in regular rows are the vessels. The smaller cavities with slightly thickened walls are either parenchymatous cells with lignified cell walls or fibres. **The Lignified Vessels, wood parenchyma and fibres constitute the elements of the Xylem of the Vascular Bundle.** Vessels lying close to the pith form the **Protoxylem** and those far away from the pith are later formed vessels and constitute the **Metaxylem.** Behind the xylem towards the periphery of the stem lie several layers of thin walled cells. Of these cells those close to the xylem are regularly arranged and are narrowly rectangular in shape. These constitute the **Cambium.**

The cells of the cambium are produced by cell divisions occurring in the initial layer or the cambium proper. The cambium is the most delicate part of the vascular bundles, and further additions of elements to xylem and phloem are brought about by the activity of the cambium layer. The irregularly grouped thin walled cells lying close to the cambium on the side of the cortex form the **Phloem** portion of the vascular bundle. The phloem is really made up of sieve tubes and parenchymatous cells. Between the endodermis on one side and phloem on the other we find a bundle of sclerenchyma. This bundle of sclerenchyma does not form part of the vascular bundle and hence we often use the term **Fibro Vascular Bundle** to denote that fibres are associated with the vascular bundle. The bundles of sclerenchyma together with the part of the medullary ray between them form a continuous ring, just outside the vascular bundles and inside the endodermis. This part is therefore the outermost part of the stele and constitutes the **Pericycle.** In stems the pericycle is usually many layered and may be uniform or may consist partly of parenchyma and partly of sclerenchyma.

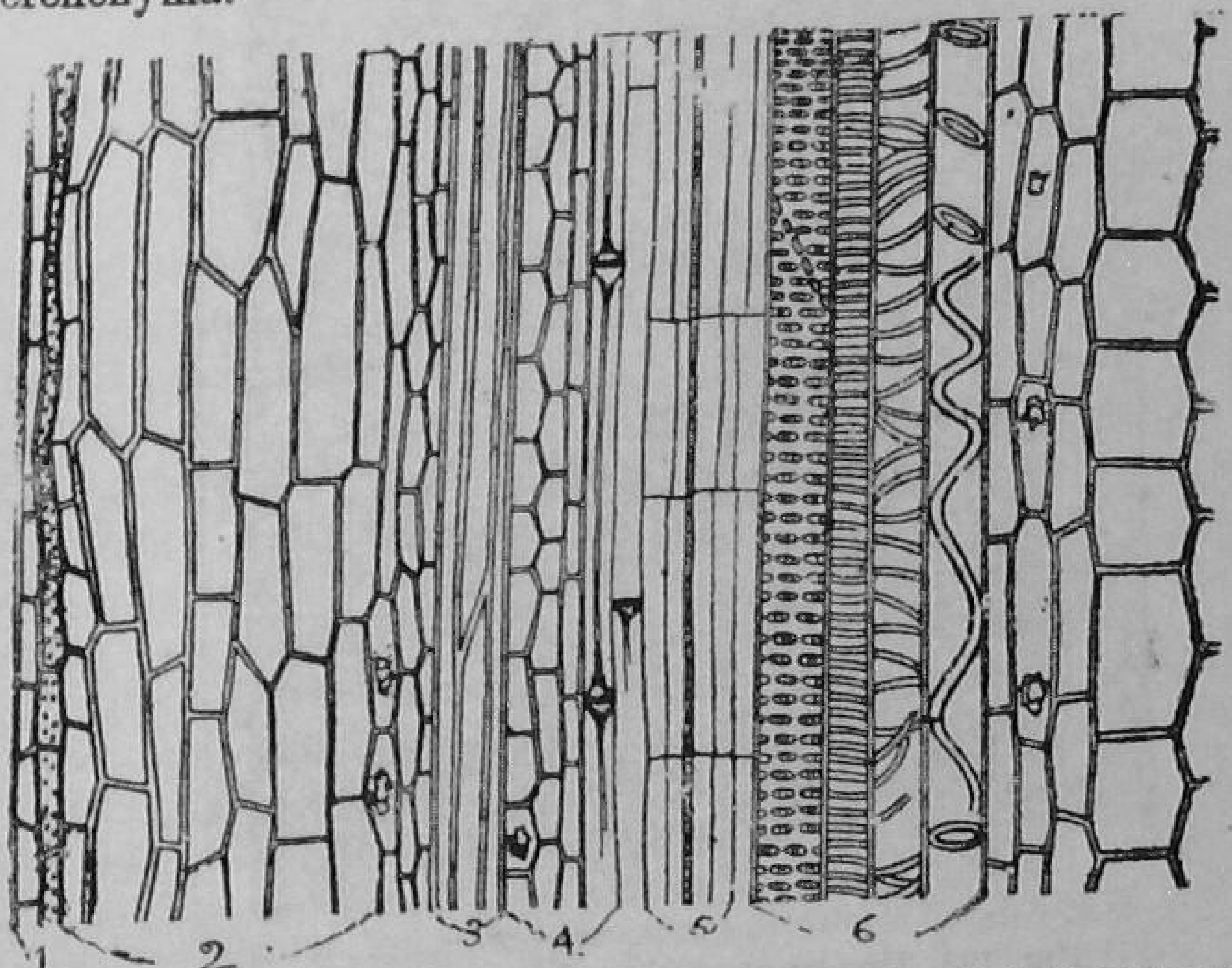


Fig. 193. Median longitudinal section of a vascular bundle in the stem of *Hibiscus cannabinus*: (1) Epidermis, (2) cortex, (3) sclerenchyma' (4) phloem, (6) xylem. *Note* The initial layer of the cambium.

To understand the nature of the elements of the various parts of a vascular bundle it is necessary to examine a median longitudinal section. Such a section of the vascular bundle of a stem is shown in figure 193. The pith and cortex consist of thin walled

parenchyma. The outermost layer of the stem consists of flattened thin walled cells and it is the epidermis. Between the cortex and the pith lie the various elements of the vascular bundle (Fig. 193) The cortex consists of somewhat elongated parenchymatous cells and next to it and inside towards the stele we find fibres. Sieve tubes occur close to the fibres and the cambium lies between them and the xylem. Pitted vessels lie close to the cambium and in front of these vessels come spiral vessels.

As already stated, the medullary rays separating the bundles are generally broad and consist of parenchymatous cells. They run from the pith to the cortex and hence they are called **Primary Medullary Rays**. As the stem gets older and older the primary medullary rays get narrower and narrower, because of the formation of new vascular bundles in the primary medullary rays. (*See* Fig.

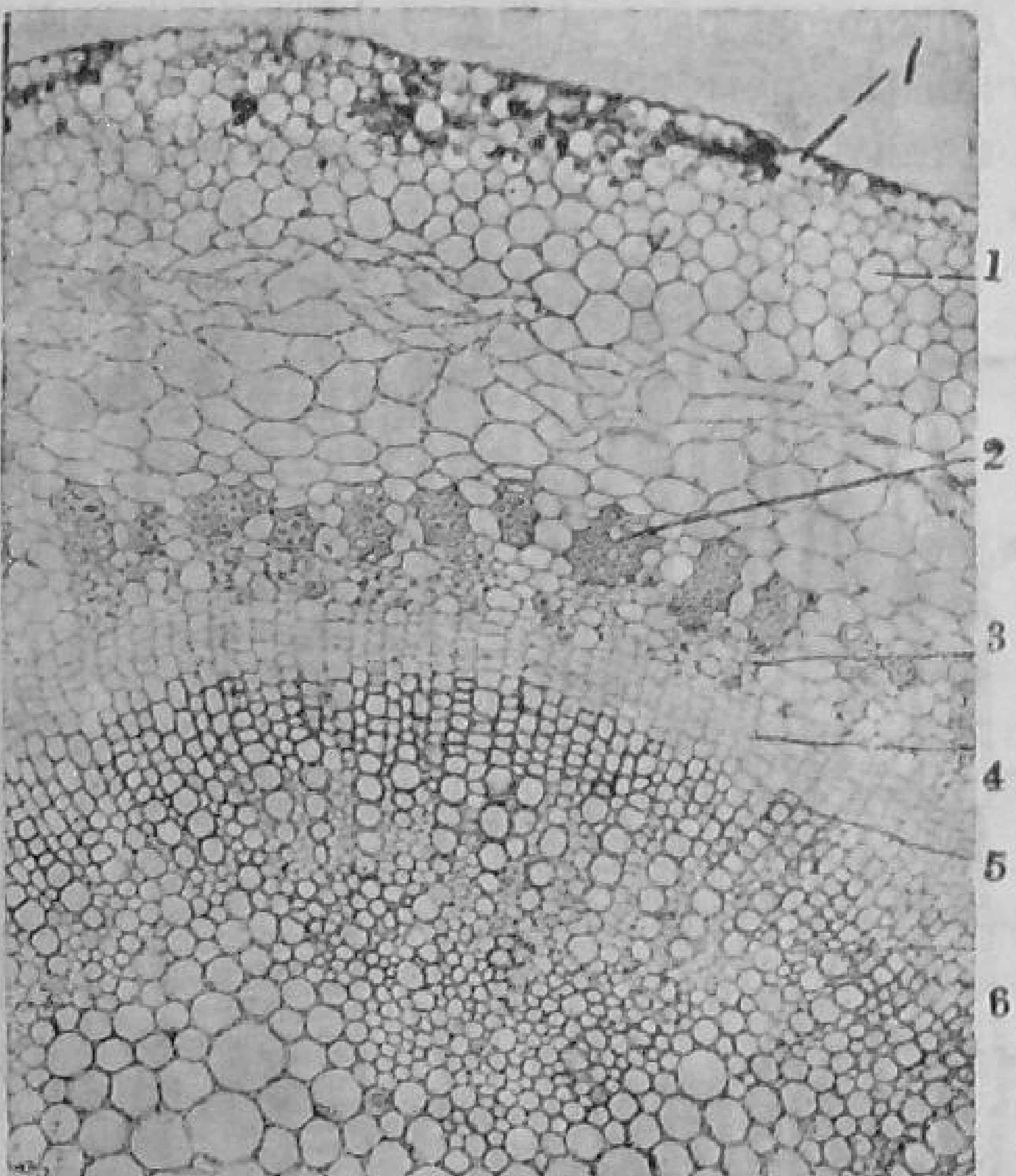


Fig. 194. Transverse section of a portion of old stem of *Hibiscus cannabinus*. (1) Epidermis, (2) sclerenchyma, (3) phloem, (4) cambium, (5) xylem, (6) medulla.

196). So long as the vascular bundles are separate, the whole of the medullary ray consists of parenchyma. But as soon as the xylem becomes a continuous ring, that part of the ray which runs through the xylem becomes differentiated into wood parenchyma

and the cells contain in most cases starch grains. Such medullary rays run right through the xylem or they may run only to a certain distance. The former are primary and the latter **Secondary Medullary Rays.**

The stem of *Hibiscus cannabinus* does not differ very much from that of *Helianthus annuus* in its internal structure. A transverse section of a very young stem of this plant is shown in figure 194. The outermost layer is the epidermis. Below this lies a narrow band of cortex consisting of a few layers of parenchymatous cells with intercellular spaces. The endodermis can be made out. The stele consists of a large amount of pith surrounded

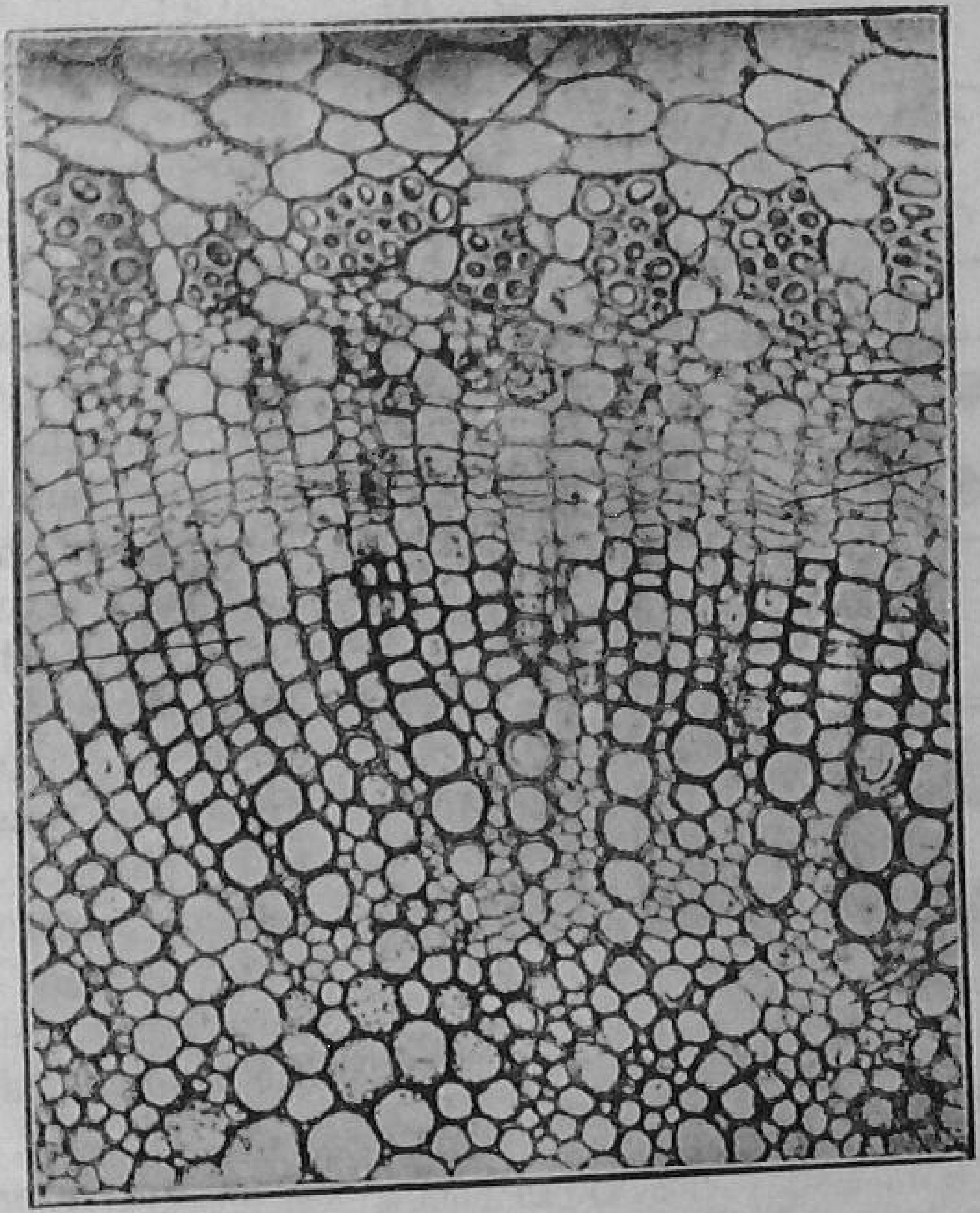


Fig. 195. Transverse section of a portion of the stele in the stem of *Hibiscus cannabinus* (1) Sclerenchyma, (2) phloem, (3) cambium, (4) protoxylem, (5) metaxylem.

by numerous small vascular bundles separated by very narrow medullary rays. The cambium is fairly broad and conspicuous. In older stems the vascular cylinder becomes quite continuous. Another striking character in this stem is the presence of groups of fibres (Hard Bast) in the phloem alternating with sieve tubes (Soft

Bast) and thin walled phloem parenchyma. The details of the structural features of this stem can be made out by reference to the figures 194 and 195.

In a transverse section of the stem of *Aristolochia bracteata*, we clearly see the epidermis, the cortex and the stele. Within the stele there are a number (5 to 11) of vascular bundles separated by very broad medullary rays. The vascular bundles consist of xylem and phloem with cambium between them. The endodermis is dinstinct because the inner layers of cells in contact with it are thick walled. Between the endodermis and the vascular bundles we find two distinct continuous bands. The layers of cells with thick walls are the fibres and instead of being in the form of separate bundles as in the stem of *Helianthus*, they form a continuous ring. Inside this ring of fibres there is a broad band of parenchyma. These two tissues (fibres and parenchyma) together constitute the pericycle here. The epidermis has a cuticle and the central part of the stele is pith. In this stem the interfascicular cambium makes its appearance gradually and slowly.

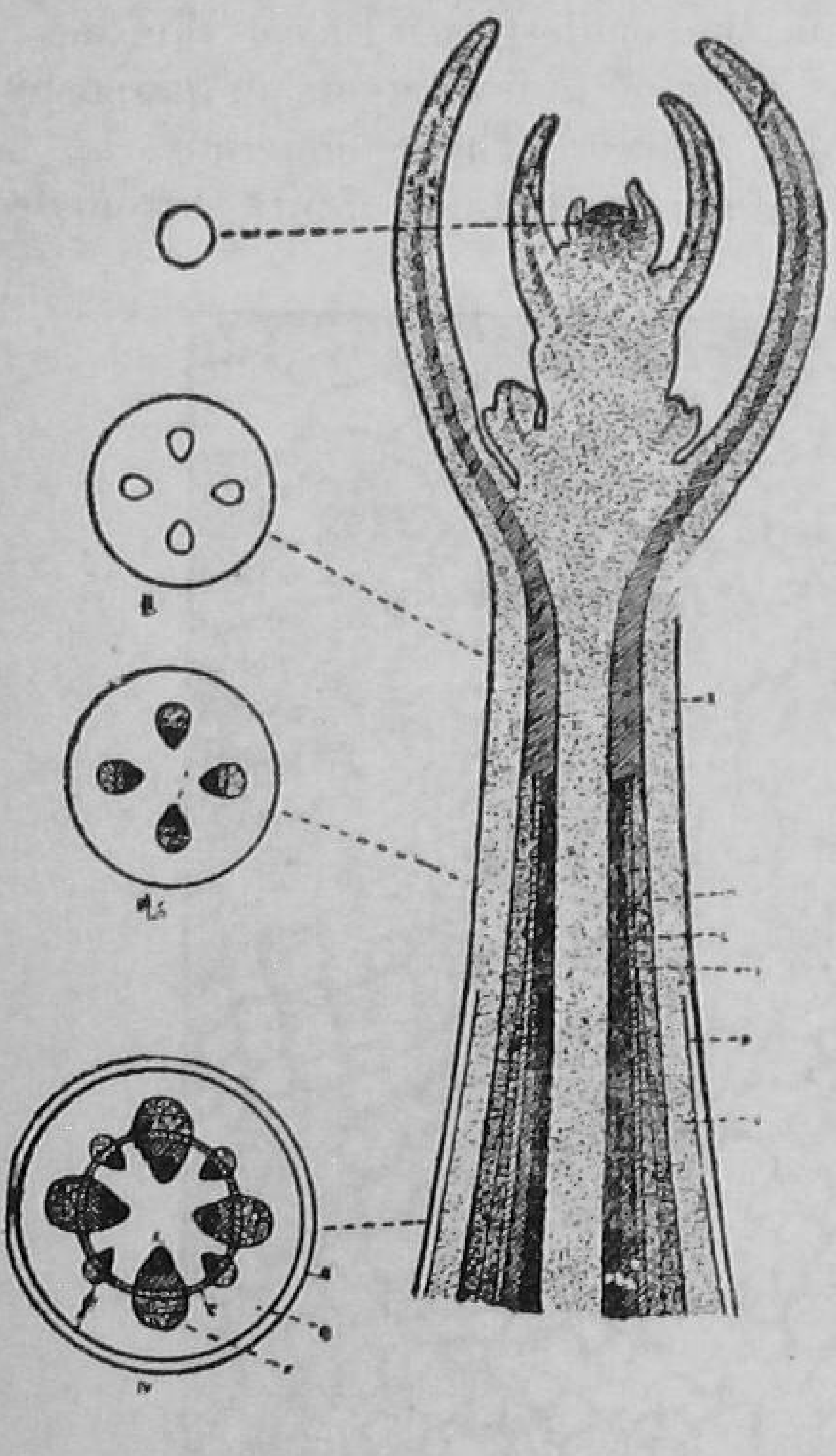
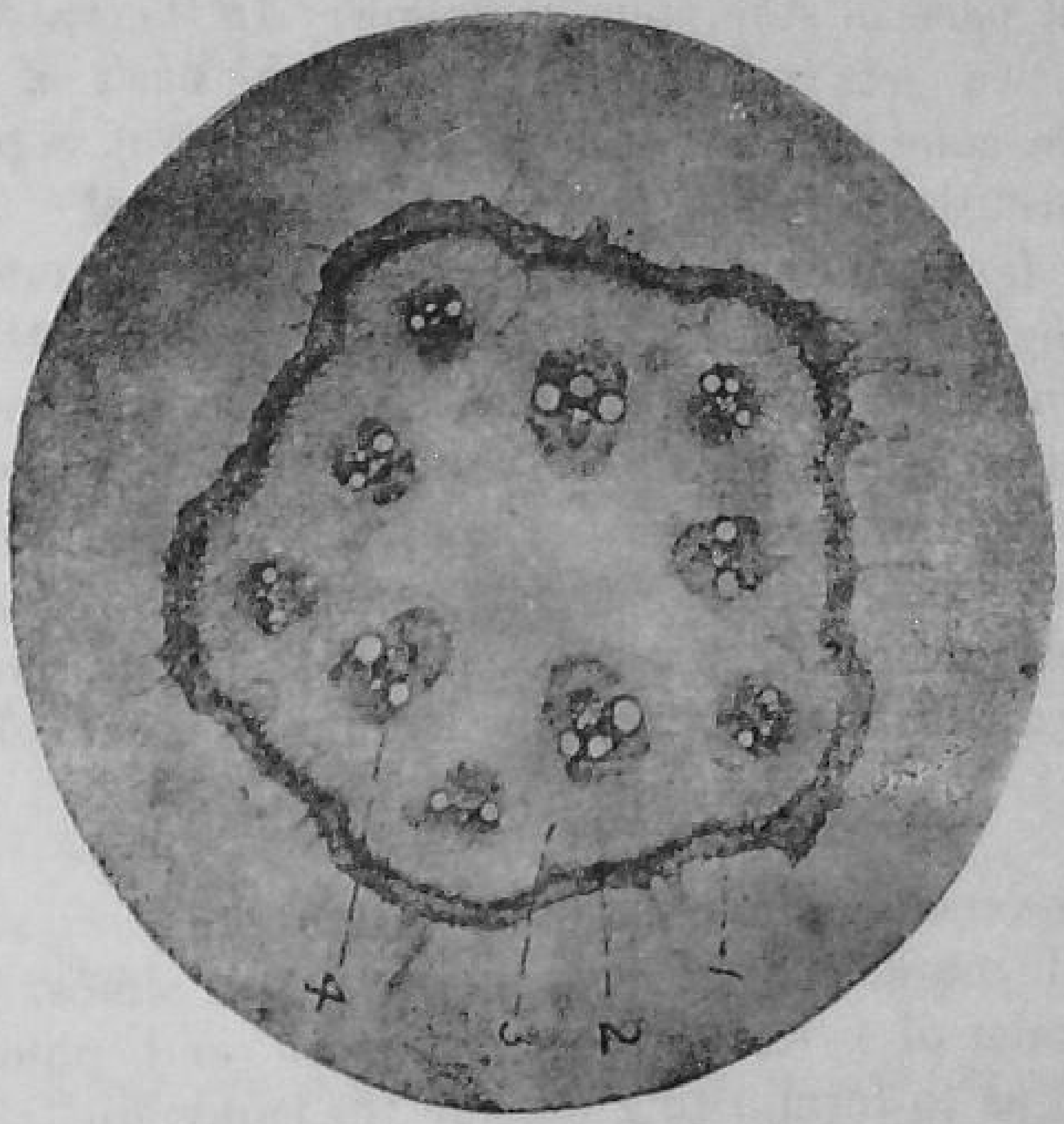


Fig. 196. Transverse and longitudinal sections of a typical dicotyledonous stem. *Note:* (1) Cells in topmost sections are all uniform (2) lower down, the cells are differentiated and primary meristems are formed: (3) lower down again vascular bundles are differentiated: (4) Still lower down, secondary thickening has taken place and secondary vascular bundles are formed.

The structure of the stem of *Curucrbita maxima* presents certain special features (Fig. 196-A). The superficial layer, like that of other stems, forms the epidermis. The epidermal cells bear hairs externally. Compared with other stems the cortex is narrow and the stele is fairly broad. The

peripheral portion of the stele abutting on the innermost layer of the cortex possesses a number of layers of sclerenchymatous



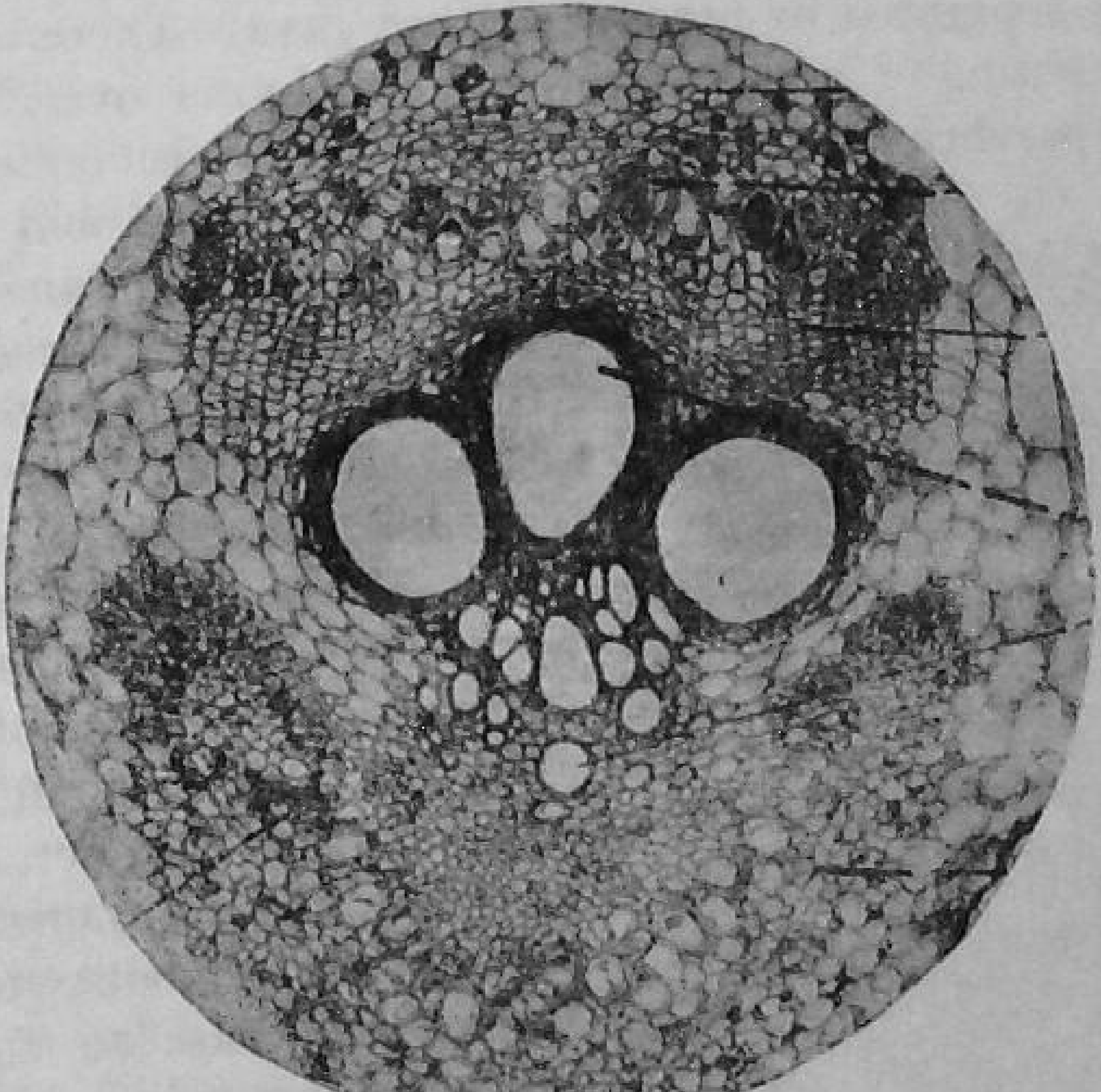


Fig. 196-A.—Transverse section of the stem of *Cucurbita maxima*. (Low power) 1. cortex: 2. sclerenchymatous ring; 3 medullary ray; 4. vascular bundle.

cells forming a continuous band running round the stem. This sclerenchymatous band with the thin walled layers of cells lying outside the vascular bundles forms the pericycle. Within the

stele there are two series of vascular bundles, of which the five outer small ones alternate with the five inner larger bundles. The central part of the stem is hollow. In the vascular bundle there are two sets of phloem, one at the back of the xylem next to the cambium and the other in front of it towards the pith. Hence the bundles are termed **Bicollateral**. The xylem vessels are fairly numerous, the larger ones being pitted vessels. Some of the pitted vessels have cells growing into their cavity and blocking the passage. Such cells growing into the cavity and blocking them are called **Tyloses**. In the phloem masses, sieve tubes are numerous and they are large. Longitudinal sections show the sieve plates and the contents of the tubes very clear. The threads passing through the pores of the sieve tube become obvious when stained with iodine or eosin or Hoffman's blue.

Secondary Growth in Thickness

A transverse section of a year old stem of *Thespesia populnea* has a well marked pith surrounded by an almost continuous hollow cylinder of xylem, a broad cambium and phloem masses arranged so as to form a ring outside the cambium. The phloem masses are separated by broad medullary rays. There is a narrow cortex consisting of a thin band of collenchyma overlying a few layers of parenchymatous cells. The epidermis is found as a superficial layer but the cells are dead and in some places it may be found ruptured. Within this dead epidermis lie layers of cells all regularly arranged and without any intercellular space. This is the **Cork Tissue**. The epidermis keeps pace with the growth in thickness of the stem up to a certain limit, and then this work of protection is done by **Cork Tissue**. Long before the epidermis is about to become dead and cease to function, a layer of parenchymatous cells in the cortex, below the epidermis becomes meristematic and a **Cork Cambium** is formed. This cambium goes on producing towards the outside **Cork Cells** forming the **Cork Tissue**.

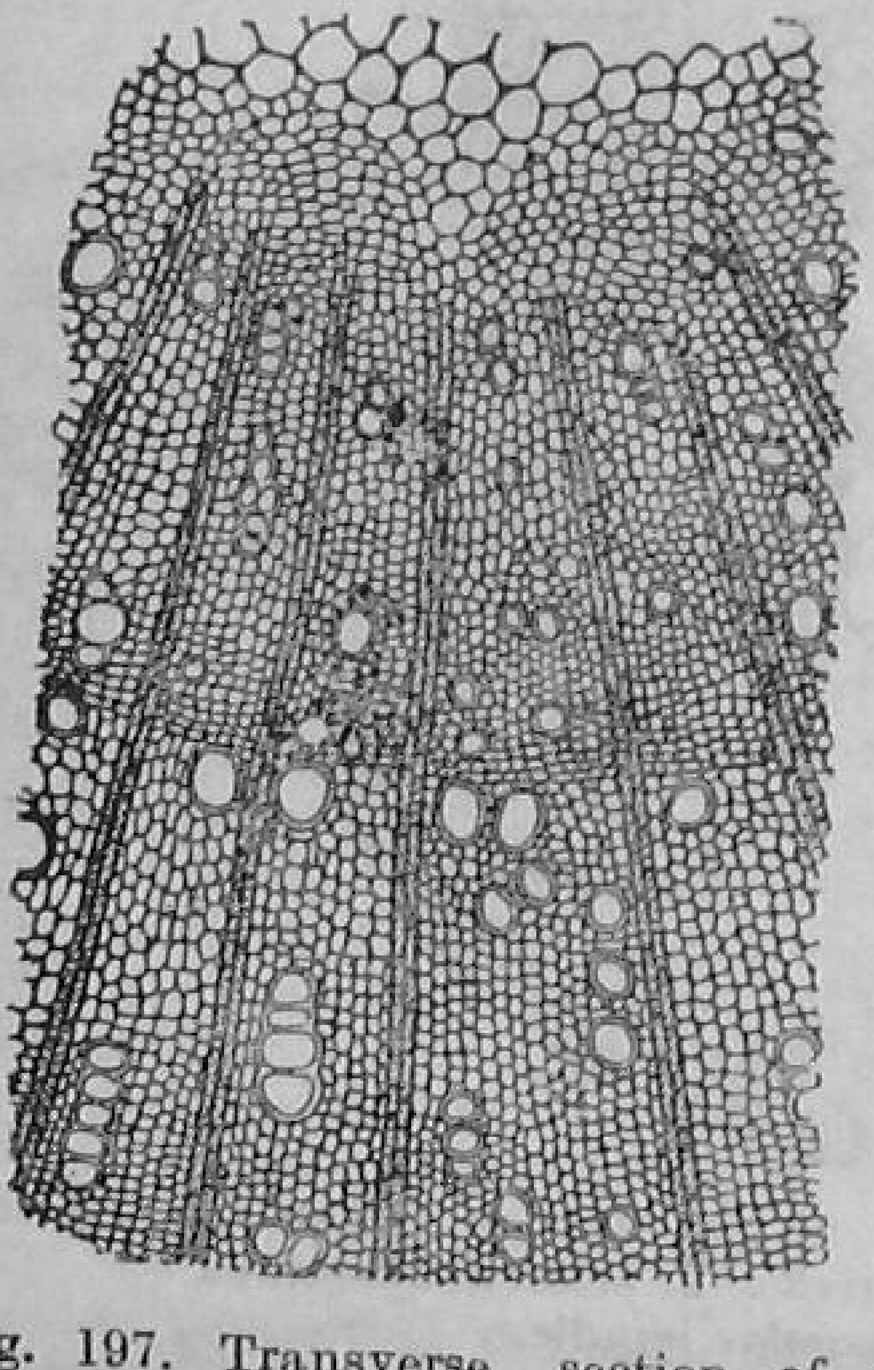


Fig. 197. Transverse section of a portion of a woody stem showing medullary rays.

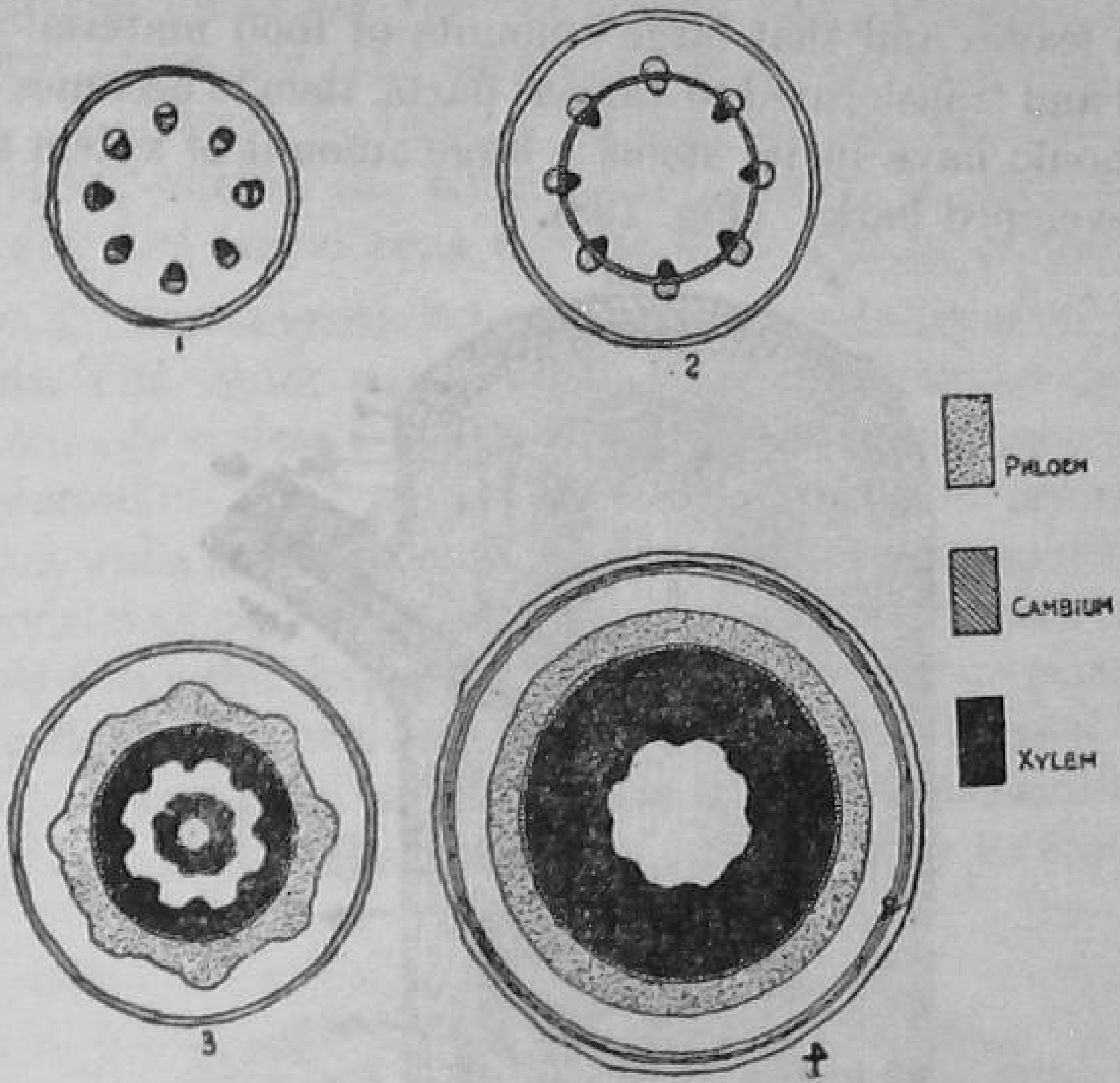


Fig. 197-A. Diagrammatic transverse section to explain secondary thickening. (*i*) Primary structure; (*ii*) Cambium active; (*iii*) early stages of secondary thickening; (*iv*) old stem.

A woody stem has fundamentally the same structure that is found in a herbaceous type of stem, though there are differences (Fig. 197). After all, the differences between a herbaceous stem and a woody stem lie in the relative proportions of the different tissues and in the formation of cork. The cambium is more active and there is a large increase in every tissue. There is provision for indefinite expansion. In a woody stem the xylem portion is the most prominent thing as it is increasing in bulk due to the activity of the cambium. The primary cortex becomes the bark by the formation of cork, fibres and sclerotic cells. What we call bark in a woody stem really consists of cork tissue, parenchyma, and fibres forming part of phloem. The bark is capable of adjusting itself admirably to the bulk of the growing stem. The medullary rays become conspicuous. They are narrow plates of tissue extending in the radial direction from the cambium to the pith or stopping short of it. Their vertical extension is not much and their ends are somewhat lenticular in shape. Inasmuch as the cells of these rays consist of pitted wood parenchymatous cells filled with protoplasm and starch, these link the phloem and the xylem and form a connected system of living tissue extending inwards and outwards. If we bear in mind that a tree has to withstand a great deal of external mechanical force, that large amounts of water pass away

from the leaves and that large amounts of food material have to be stored and translocated to various parts, then it becomes obvious that it should have in its stems a large amount of xylem and also a well developed bark. (Fig. 198).

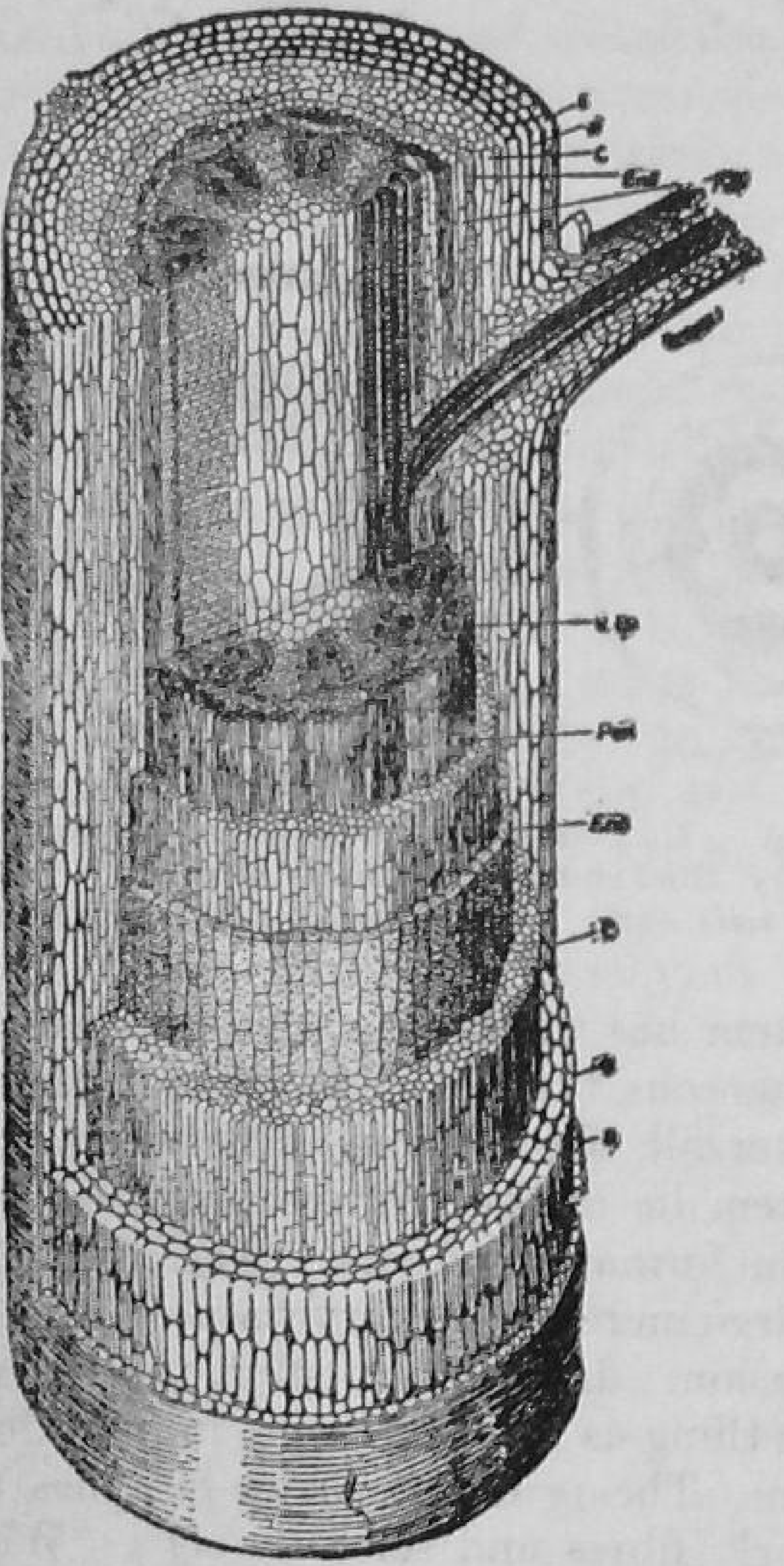


Fig. 198. Transverse and longitudinal sectional views of a typical dicotyledonous stem. *Note* how the different tissues surround one another.

Monocotyledonous Stem

The structure of the stem of monocotyledons is different from that of the dicotyledonous stems. As types of monocotyledons the stems of cereals and grasses may be examined. (Fig. 199-204). In a transverse section of the stem of a grass the vascular bundles are found scattered amidst a mass of parenchymatous cells. The vascular bundles consist of only xylem

and phloem, without the cambium, and so there cannot be secondary thickening, and such bundles are called closed vascular bundles. A distinct medulla is wanting as the vascular bundles are scattered within the stele. The cortex is distinct though narrow and the endodermis can be made out in certain stems.

The stem is covered externally by a single layer of cells, the epidermis. The outer wall of these cells is thickened due to the deposition of cuticle. Here and there stomata occur. Below this epidermis in many plants we find two or three layers of cells whose cell walls are thickened. In monocotyledonous stems these layers consist of sclerenchymatous tissue. These layers below the epidermis form the **hypodermis**. Then we have a mass of thin walled cells amidst which we find a number of closed vascular bundles. These bundles are surrounded by sclerenchymatous sheaths (Fig. 200). The xylem elements are two to four only in

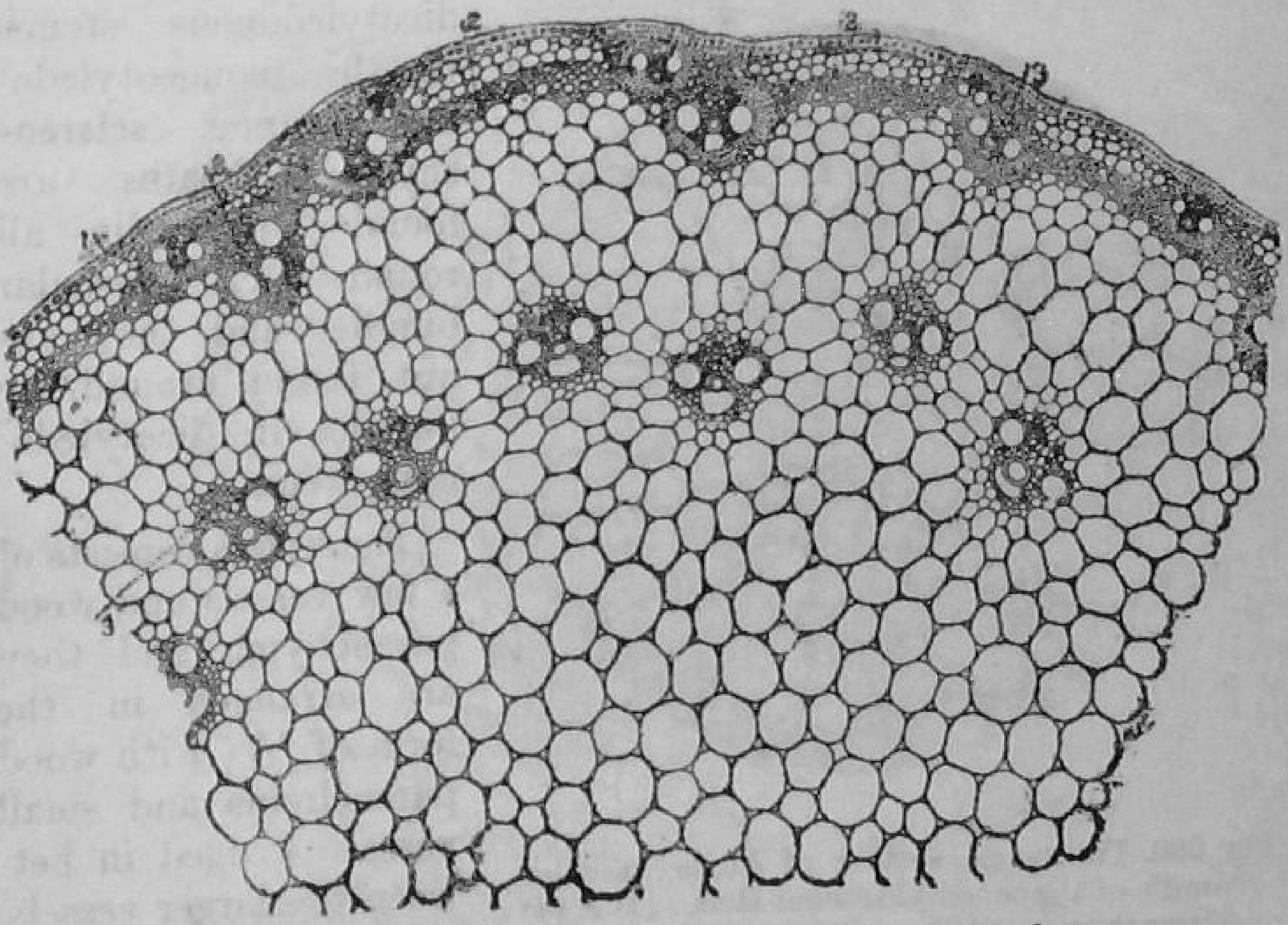


Fig. 199. Transverse section of a portion of the stem of *Setaria glauca*. (1) Epidermis, (2) sclerenchyma, (3) vascular bundles.

most stems and the lateral ones are reticulated or pitted. The central xylem elements are narrower and they are annular and spiral vessels. In the phloem portion we have only sieve tubes and companion cells, without any phloem parenchyma. The later formed sieve tubes alone persist in the phloem. (Fig. 200). Thus a monocotyledonous stem is far more simple in structure and has (1) the epidermis,(2) a ground tissue partly parenchymatous

and partly sclerenchymatous, and (3) the vascular bundles scattered in the ground tissue.

Difference between a dicotyledonous stem and a monocotyledonous one.—The epidermis is cuticularised in both, but hairs are common in dicotyledonous stems and less common in monocotyledons. The hypodermis is sclerenchymatous in monocotyledons and in dicotyledons it is collenchymatous at least where young. In the monocotyledonous stems we can make out very clearly the epidermis, sclerenchyma and the ground tissue only, but in the dicotyledonous stem we can distinctly make out the epidermis, the cortex with its endodermis, the pericycle, medullary rays, vascular bundles and pith. The vascular bundles are **open** in the dicotyledonous stems and they are **closed** in the monocotyledonous ones. No phloem parenchyma can be seen in the stems of monocotyledons, though it is of common occurrence in the vascular bundles of dicotyledonous stems. In the monocotyledonous stems **sclerenchyma sheaths** are found practically all round each vascular bundle, and they are not found around the bundles in dicotyledonous stems.

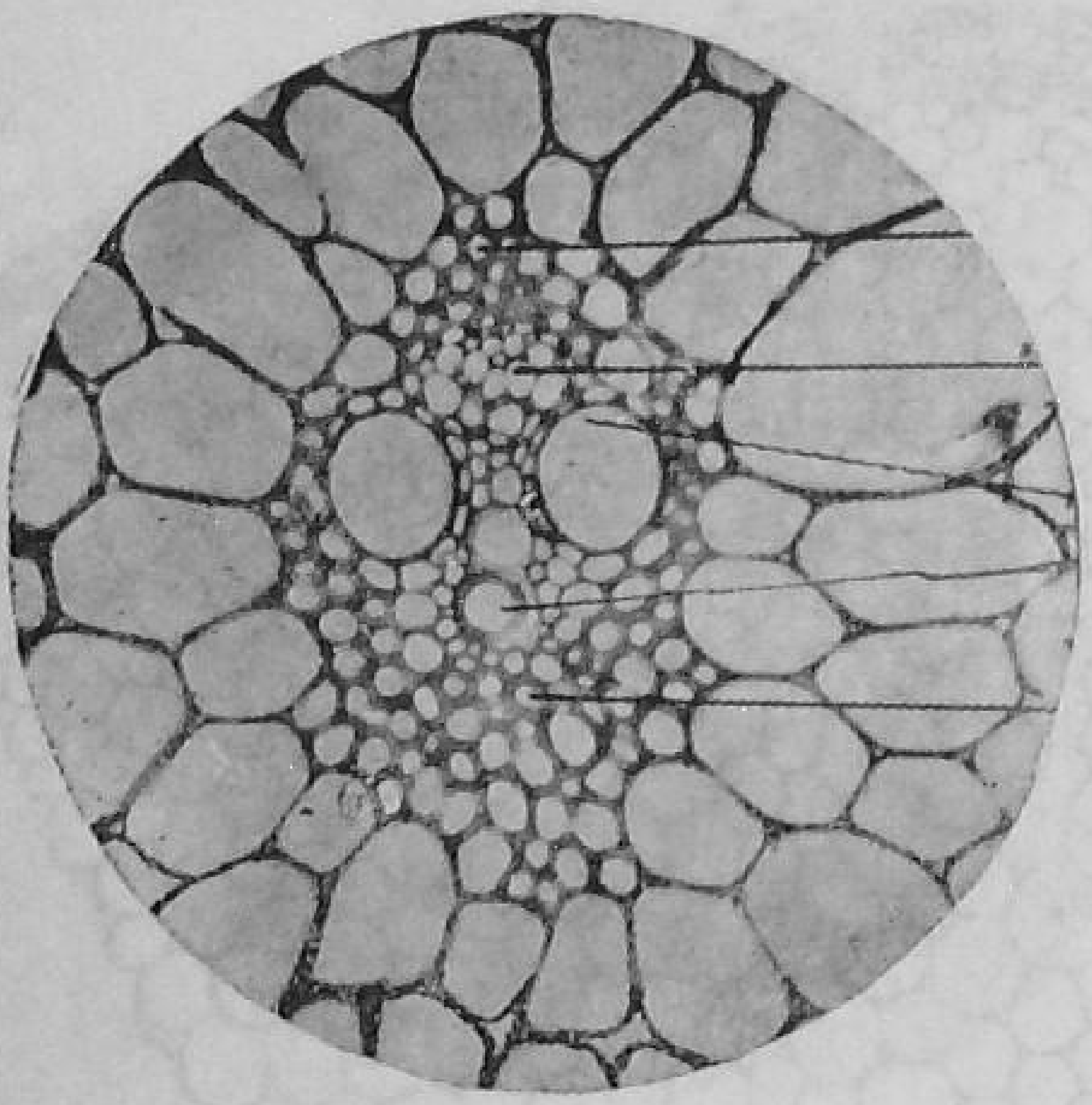


Fig. 200. Transverse section of single vascular bundle of a monocotyledonous stem : (1) & (4) sclerenchymatous fibres, (2) phloem (2) xylem.

The xylem consists of a few vessels and wood parenchyma and they are arranged in the form of 'V' with wood parenchyma and small vessels wedged in between the larger vessels. The phloem lies close to the xylem. All round the bundle we find fibres forming a kind of sheath which is well developed.

The cell walls of the cells of the epidermis and of one or two layers of the cortex lying immediately beneath the epidermis become thickened. These layers go by the name **hypodermis.** Further the sclerenchymatous sheaths of the vascular bundles lying at the peripheral portion of the stem are generally very broad

and much strengthened. By all this arrangement the outer portion of the stem becomes hard and stiff enabling it to withstand the train of wind and weight.

From what we have learnt about the structure of stems and roots, we know that secondary thickening takes place in both roots and stems of dicotyledonous plants. Under normal conditions the formation of new cells causing an increase in their number, which is essential for the formation of new elements for the various tissues, is the work of the cambiums. But under abnormal conditions parenchyma that has become a permanent tissue may once again become active and give rise to different kinds of tissues. When a stem is injured various tissues are exposed to the air. Most of the cells of the cortex are living cells and so, when pressure is removed by injury, all these cells swell and some of them lying somewhat deeper begin to divide. As a result of this activity a mass of

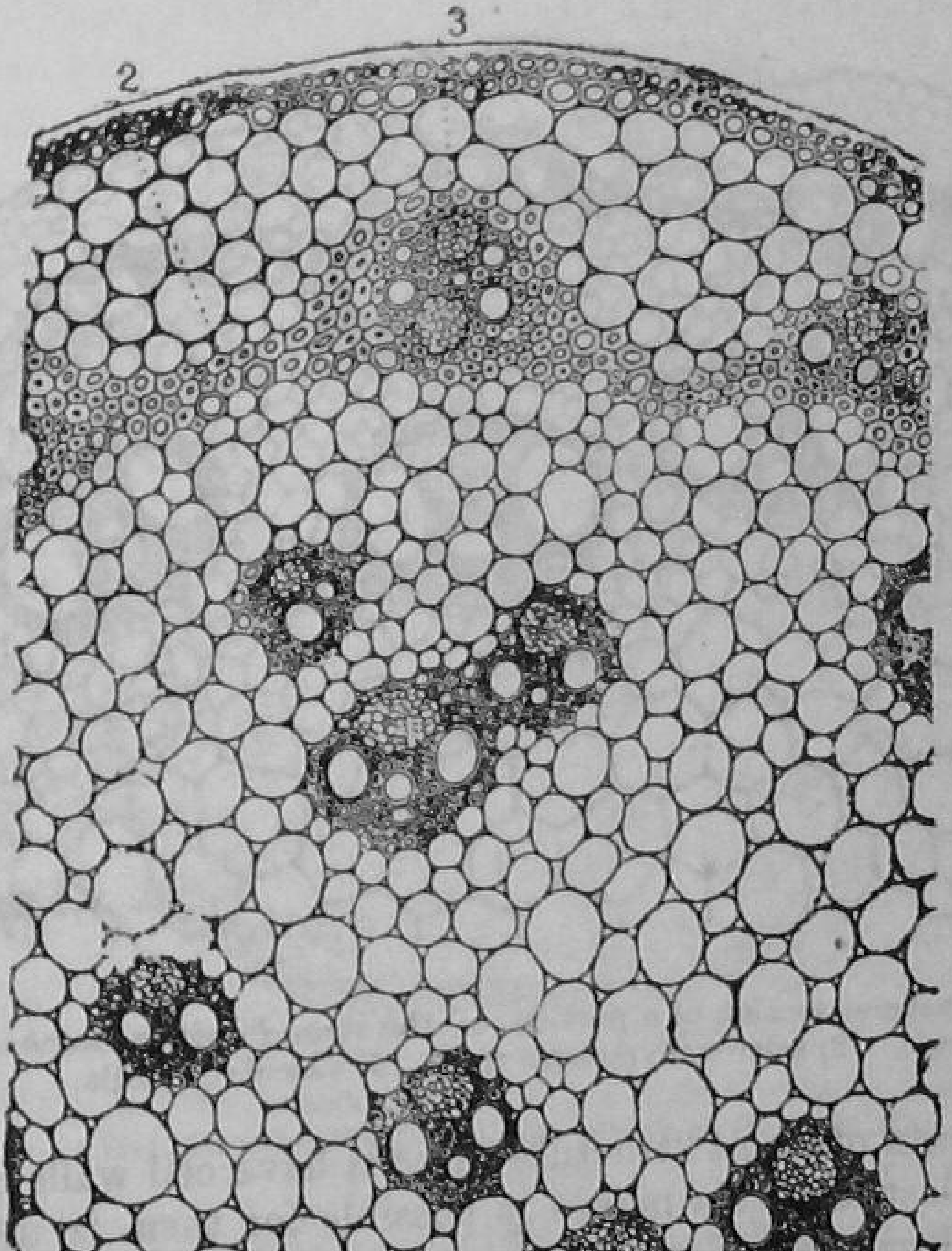


Fig. 201. Transverse section of a portion of the stem of *Cenchrus ciliaris*. (1) Epidermis, (2) sclerenchymatous ring, (3) vascular bundle.

cells is formed at the injured area and the outermost cells become changed into the protective tissue, cork. This mass of cells brought into existence by this abnormal activity is spoken of as **callus** and the process is termed **callus formation**. All wounds caused in the parts of plants are healed by this process only.

Mechanical tissues : And their arrangement in the plant body.—All plants growing normally amidst a number of varying external physical conditions have to maintain their form, if they are to do their functions properly. They must also be able to resist those stresses and strains that are likely to befall them in their ordinary course of life. The construction of the plant body must be such as to enable it to ward off the effects of strong winds and at the same time bear the weight of the branches, twigs and leaves.

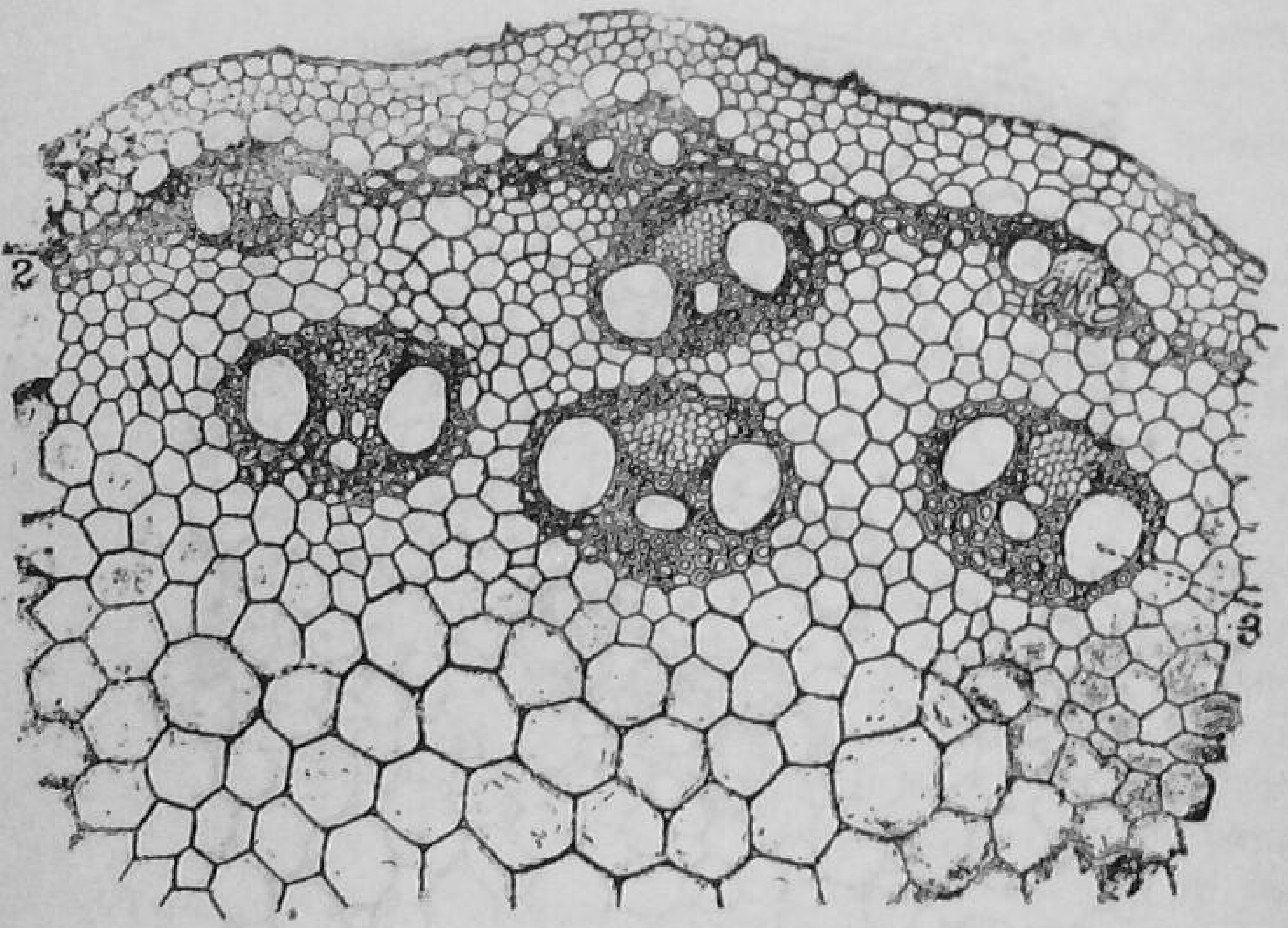


Fig. 202. Transverse section of a portion of the stem *Panicum isachne*. (1) Epidermis, (2) sclerenchymatous ring, (3) vascular bundle.

The units of plant structure or cells have cell walls enclosing the protoplast and this makes it possible for them to secure the necessary firmness. Very young parts of plants are capable of maintaing their rigidity and firmness, as the cells of which they are composed remain in a turgid condition. Older parts have developed in them specific mechanical tissues and such tissues are the **collenchyma** and the **sclerenchyma**.

As all the parenchymatous cells in the younger parts of plants are active, it is necessary to have some kind of mechanical tissue which would give rigidity and at the same time be elastic enough to allow the cells to grow. Collenchyma is just the tissue suited for young herbaceous stems. Collenchymatous cells do not impede the growth in length, but instead they themselves grow with the growth of the part they support, offering a persistent though plastic resistance. The position of collenchyma is inside the epidermis and this gives it a full mechanical effect.

The sclerenchyma is undoubtedly the most characteristic mechanical tissue. The stem, the leaf and the root secure the necessary mechanical advantage by the proper distribution of sclerenchyma. The stem is cylindrical and so it is able to withstand the action of wind. It is woody and this helps it in bearing the weight.

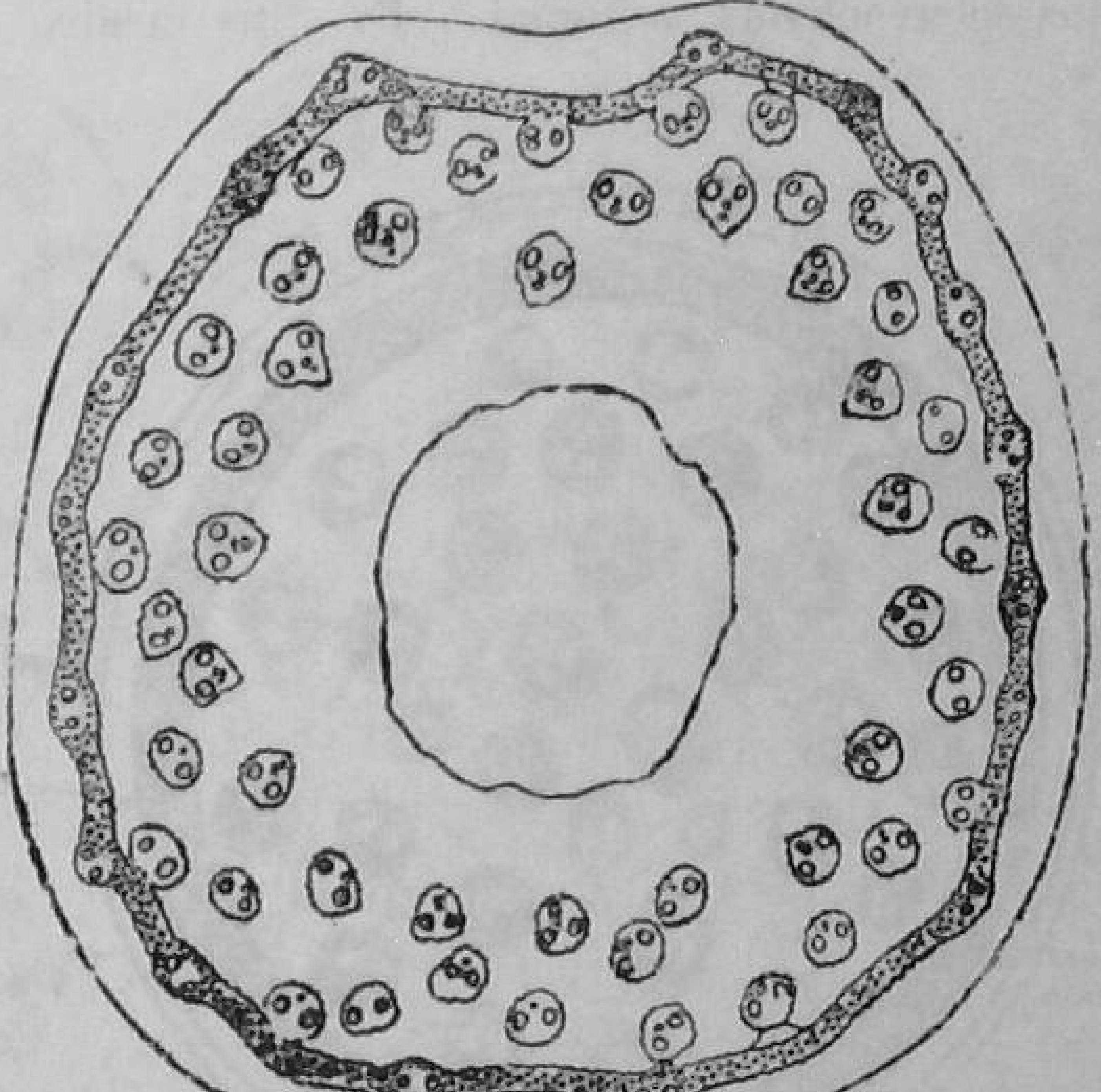


Fig. 203. Transverse section of the stem *Eragrostis interrupta* showing the peripheral sclerenchymatous ring.

The mixed xylem tissues and the sclerenchyma distributed in various places contribute in varying degrees to the mechanical effect.

The fibres forming a sheath around the vascular bundles of the monocotyledonous stem and the groups of fibres forming a

part of the pericycle in the stems of sunflower, *Cucurbita* and *Aristolochia* play a very important part in the life of the plant. These sclerenchmatous bands enable the stems of these plants to withstand the strain of wind. If we closely observe the disposition of the fibre bundles in these stems, we notice that the stems are strictly comparable to a hollow cylinder with very great firmness and rigidity at the periphery. A hollow cylinder is really a combination of several girders. In the stems of grasses the mechanically effective tissue, sclerenchyma, is found distributed towards the periphery. We find continuous sclerenchymatous bands in the stems of some grasses at the periphery with many vascular bundles imbedded in them.

The leaf has an expanded structure which when leaves are subjected to winds, is absolutely necessary to perform its functions the crushing of the mesophyll is effectively prevented, by the network of veins. In many leaves the veins are arched and at the margins sclerenchyma is found. By this means, marginal

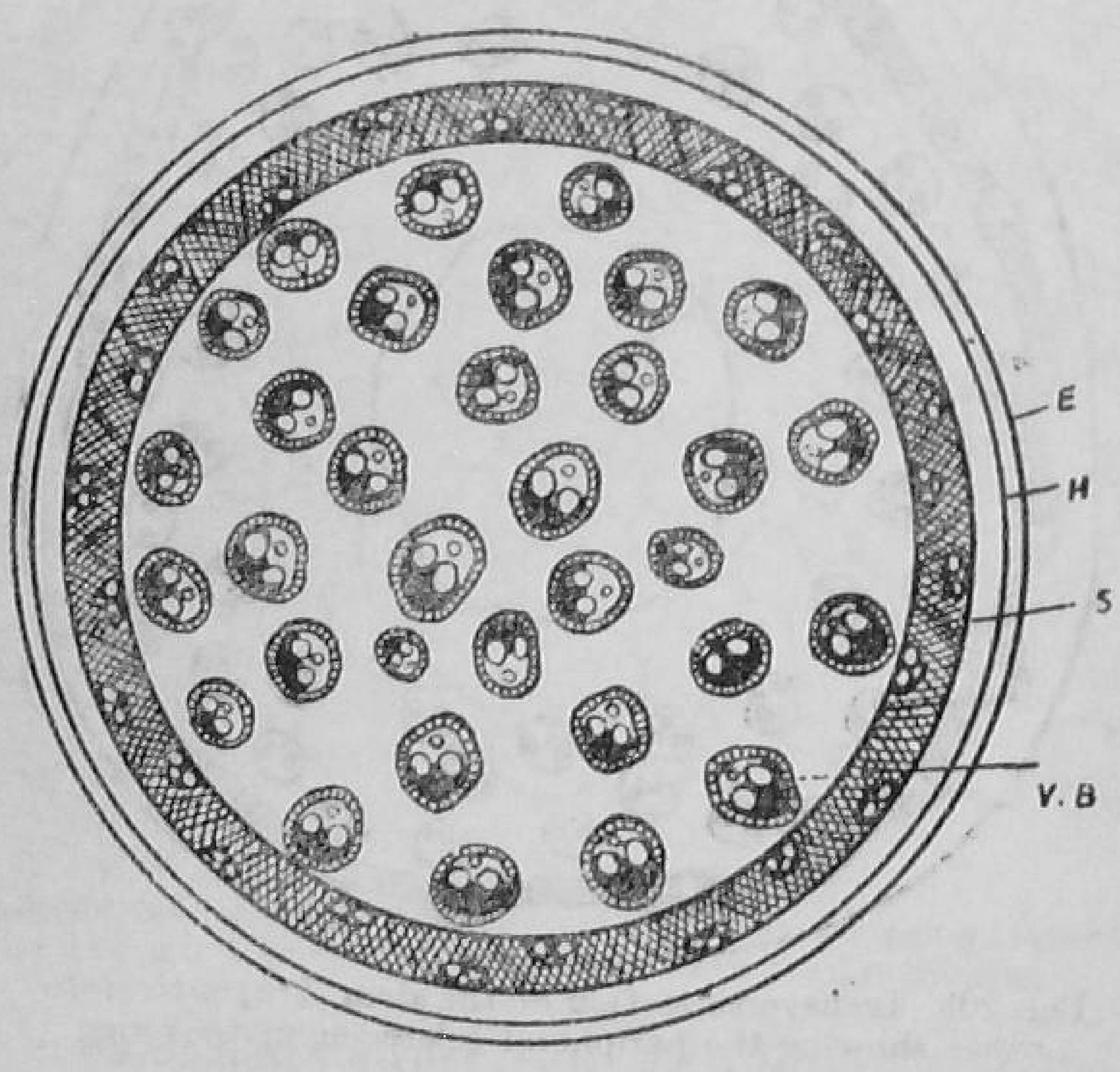


Fig. 204. Diagrammatic cross sectional view of stem of a grass. E. Epidermis, H. Hypodermis S. Sclerenchyma ring. V. B. Vascular bundle. *Note* that there are a large number of vascularbundles, scattered in arrangement and each bundle is surrounded by sclerenchyma ring, and consists of xylem and phloem elements and there is no cambium (closed bundle).

tearing of the leaves is effectively prevented. The lower and upper epidermis also form a firm skin over the mesophyll. In the leaves of monocotyledons, especially grasses, sclerenchymatous bands follow the veins on either side forming with each girder.

Roots are subjected to longitudinal tension, as they bear the weight of the shoot which is swayed by winds. To enable the roots to resist the longitudinal tension the central core becomes hardened. In some roots, especially those of dicotyledons, the central pith portion is filled with xylem elements. In monocotyledonous roots the primary xylem groups do not reach the centre and in these cases the parenchyma in the centre of the pith changes into hard cells by lignification of the cell walls. So in these roots also the central core becomes welded together into a solid mass to offer resistance effectively.

Transition from Root to Stem.—The xylem and phloem strands in roots are situated side by side on different radii in the

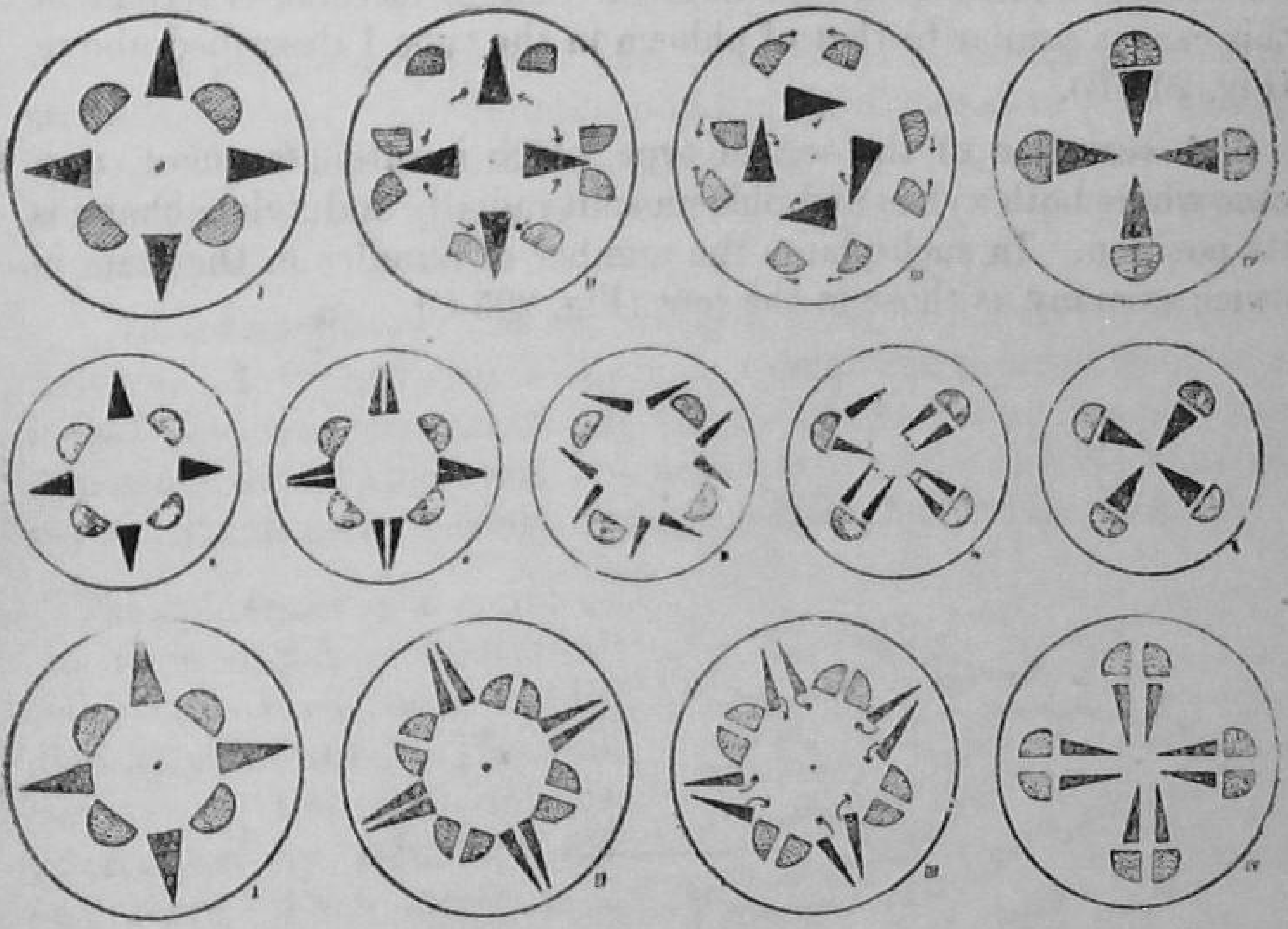


Fig. 205. Transition from root to stem. (A) Xylem rotates by 180°, follows a straight course & phloem divides. (B) Xylem divides, rotates by 180°, and adjacent strands unite. Phloem continues its straight course. (C) Both xylem and phloem divide. Xylem rotates by 180°.

root whereas they are collateral in the stem. The vascular tissues of root and stem are all the same continuous. It is therefore clear that they shift positions at the junction of root and stem in the seedling *i.e.*, at the hypocotyl region. The radial arrangement of

xylem and phloem in the root becomes collateral arrangement in the stem. It may be pointed out here that the epidermis and cortex are continuous from root to stem and the change of position takes place in the vascular tissues only. There are two main types of transition, and this generally takes place at the top of the root, hypocotyl or at the point of insertion of the cotyledons.

Two main types of transition recognised are—

(1) The xylem strand rotates by 180° and becomes endarch in the stem from being exarch in the root. It follows a straight course from root to stem, while the phloem strands of root divide radially into two, separate tangentially, the adjacent halves unite and come to lie externally to the xylem (Fig. 205-A).

(2) Xylem strands split radially into two, rotate by 180° and become endarch in the stem. Xylem strands separate tangentially, the halves from adjacent halves unite and change their positions to become internal to the phloem which latter continues its straight course from root to stem. The behaviour of xylem in this case is similar to that of phloem in the type 1 described above (Fig. 205-B).

A variation of the second type which is often frequent, is a case where both xylem and phloem split radially and xylem changes its position. In such plants the number of bundles in the stem is twice as many as those in the root (Fig. 205-C).

CHAPTER XV

INTERNAL STRUCTURE OF LEAVES

Leaves arise as lateral protuberances at the growing point of the stem. The very young leaf in its embryonic stage occupies only a small portion of the surface of the growing point, especially when the leaves are alternate. So a large number of leaves may arise within a small area. A whorl of leaves arises at first as a ring and leaves appear later as distinct structures. The embryonic protuberances which develop into leaves grow at their tips at first, at any rate more rapidly at the tip than at the base. So the upper portion of the leaf is first developed. Therefore the developing leaves protect the younger parts of the growing end of the stem. The leaf base continues its growth long after the formation of the blade and until the leaf is fully developed.

The petiole usually resembles the stem in its internal structure in angiosperms. The vascular bundles are disposed in it as an arc open inside. These bundles are without cambium, as no secondary thickening is required. In the cortex the collenchyma may be prominent.

In foliage leaves the net work of veins is a very prominent feature. A typical leaf blade has a **dorsiventral** structure. In a leaf blade we can make out three distinct parts, namely, the upper and lower epidermis, the network of veins and the mass of parenchymatous cells constituting the **Mesophyll** of the leaf.

The epidermis is a continuous layer consisting of flattened cells with their outer walls distinctly cutinised. The continuity of the epidermis is interrupted by **stomata** here and there. Each stoma is a pore bounded by a pair of semilunar cells called the **guard cells**. There are two types of guard cells, namely, the one found in the majority of flowering plants and the other, occurring in grasses and sedges. In the former type the guard

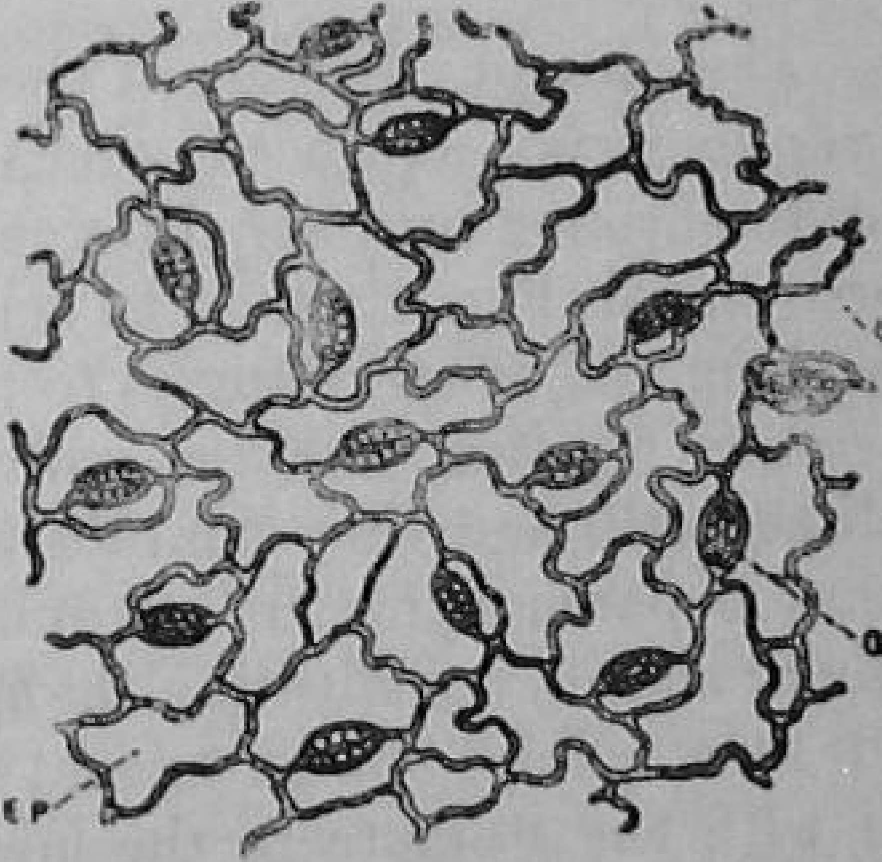


Fig. 206. Epidermis from lower surface of *Dobichos lablab* leaf. cw : cell wall ; Gc : guard cell ; Ep : Epidermal cell.

cells are semilunar (Fig. 206) and in the latter they are dumbbell shaped (Fig. 207). Chloroplasts occur in the guard cells while the epidermal cells are generally free from them. Guard cells are capable of altering the size of the pore by changing their shape. Stomata are found in large numbers in the lower epidermis although there are leaves having them on both sides.

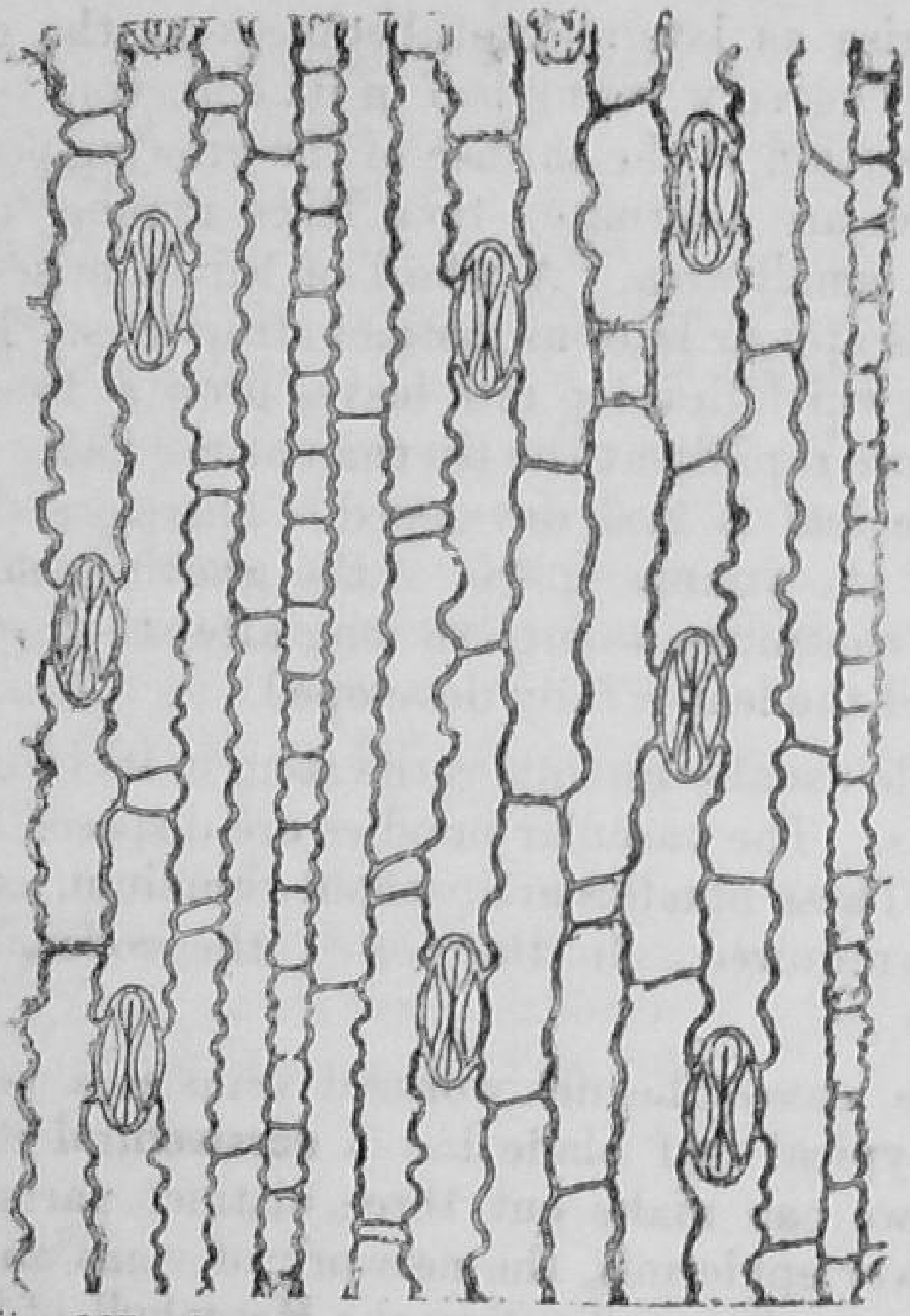


Fig. 207. Lower epidermis from the leaf of *Panicum isachne*.

The mesophyll tissue of the leaf lying between the upper and lower epidermis and occupying the meshes of the network of veins is differentiated into two different groups of cells, making the blade dorsiventral (Fig. 208). The cells lying below the upper epidermis are elongated at right angles to the surface of the leaf and lie close together forming one or more layers. These cells are called **palisade cells** and they contain abundant chloropasts. Below the palisade parenchyma lie irregularly shaped cells with wide inter cellular spaces, constituting the **spongy parenchyma**. The numerous wide intercellular spaces present in spongy parenchyma are connected with the stomata in the lower epidermis. Chloro-plasts are present in the cells of spongy parenchyma also, but not so abundant as in palisade cells. On account of the abundance of chloroplasts in the cells of the mesophyll these cells are often called **chlorenchyma**.

This distinction of the mesophyll into compact palisade parenchyma and spongy parenchyma, is liable to variations according to the habit and the species of the plant. In the leaves of a plant growing in an open place exposed to the sun, the palisade parenchyma will be deep and will consist of several layers of cells, *i.e.*,

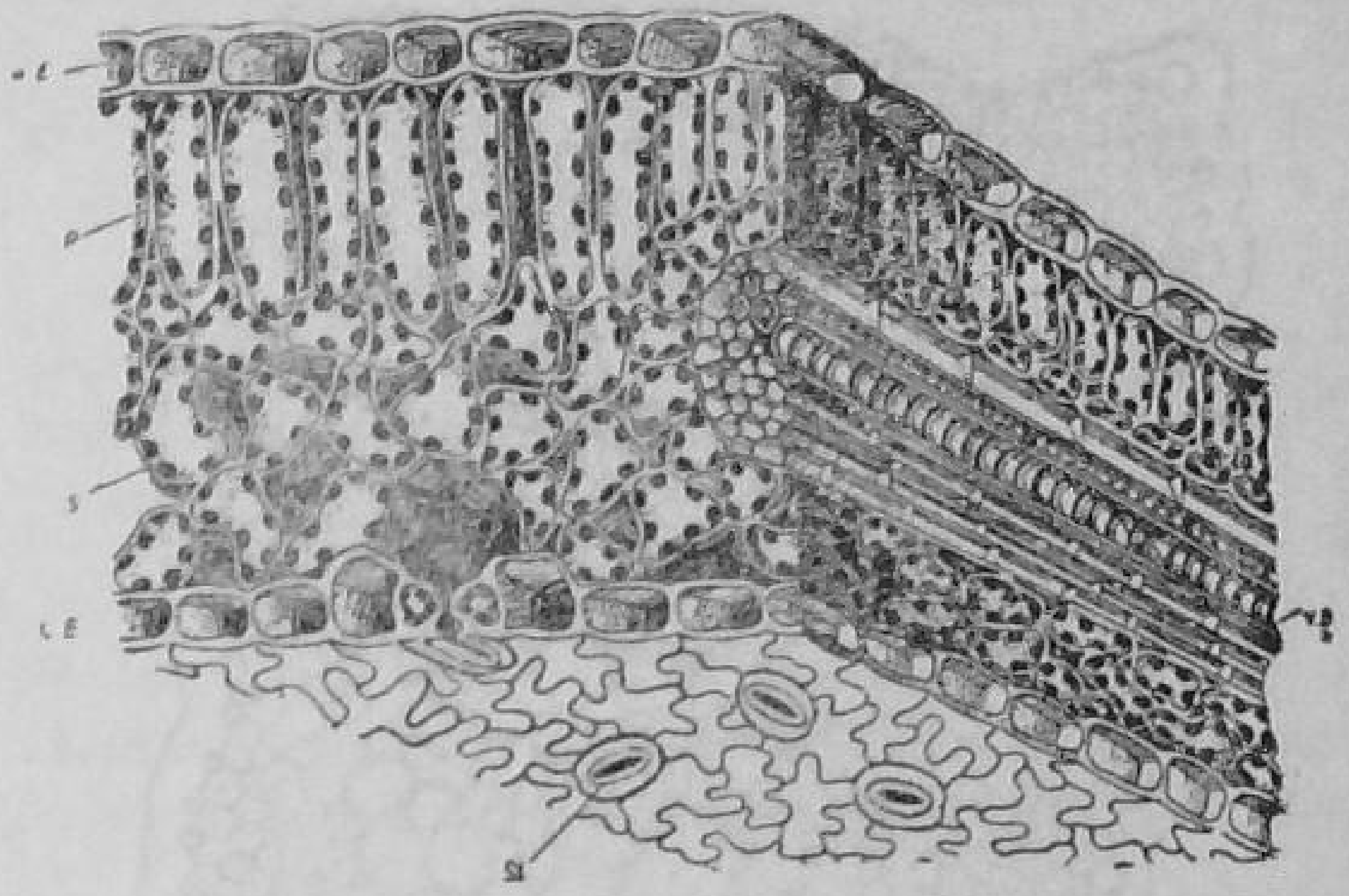


Fig. 208. Structure of typical dorsiventral type of leaf.

leaves of *Nerium*, *Calotropis* and the *banyan*. Plants growing in shady place have leaves with a single layer of palisade cells, *i.e.*, *Vigna*, and *Dolichos*. In the case of plants whose leaves are exposed to the light of the sun on both sides, the mesophyll presents no differentiation into palisade and spongy parenchyma. The leaves of grasses do not show this differentiation, but the whole of the mesophyll consists of compactly arranged parenchymatous cells. Some of the cells of the epidermis (especially in the upper epidermis) of the leaves of most grasses become larger and they are capable of containing large quantities of water. These cells are called *Motor Cells* (Fig. 209 & 210) and they help in the rolling up of the leaf. When turgid, the leaf is expanded and when they become flaccid, the leaf rolls itself up.

The veins of the network of the leaves are the continuations of the vascular bundles of the stem. Vascular bundles traversing the stem enter the petioles at the nodes, and ramify and anastomose in the blade forming the characteristic network of the leaf. The vascular bundles in large veins have xylem and phloem with the full complement of their elements, and the bundles in the smaller veins contain fewer elements. The xylem is directed towards the upper and the phloem towards the lower surface of the leaf. The bundles get smaller and simpler in structure as the veins go on branching into smaller ones. The finer ultimate branches of the

network end blindly and they consist of only reticulate and spiral tracheids. One or two sieve tubes much reduced, but with complete companion cells, may be found associated with the xylem elements. However, they stop short of the very ends of the ultimate branches. The vascular bundles in the veins are surrounded by a

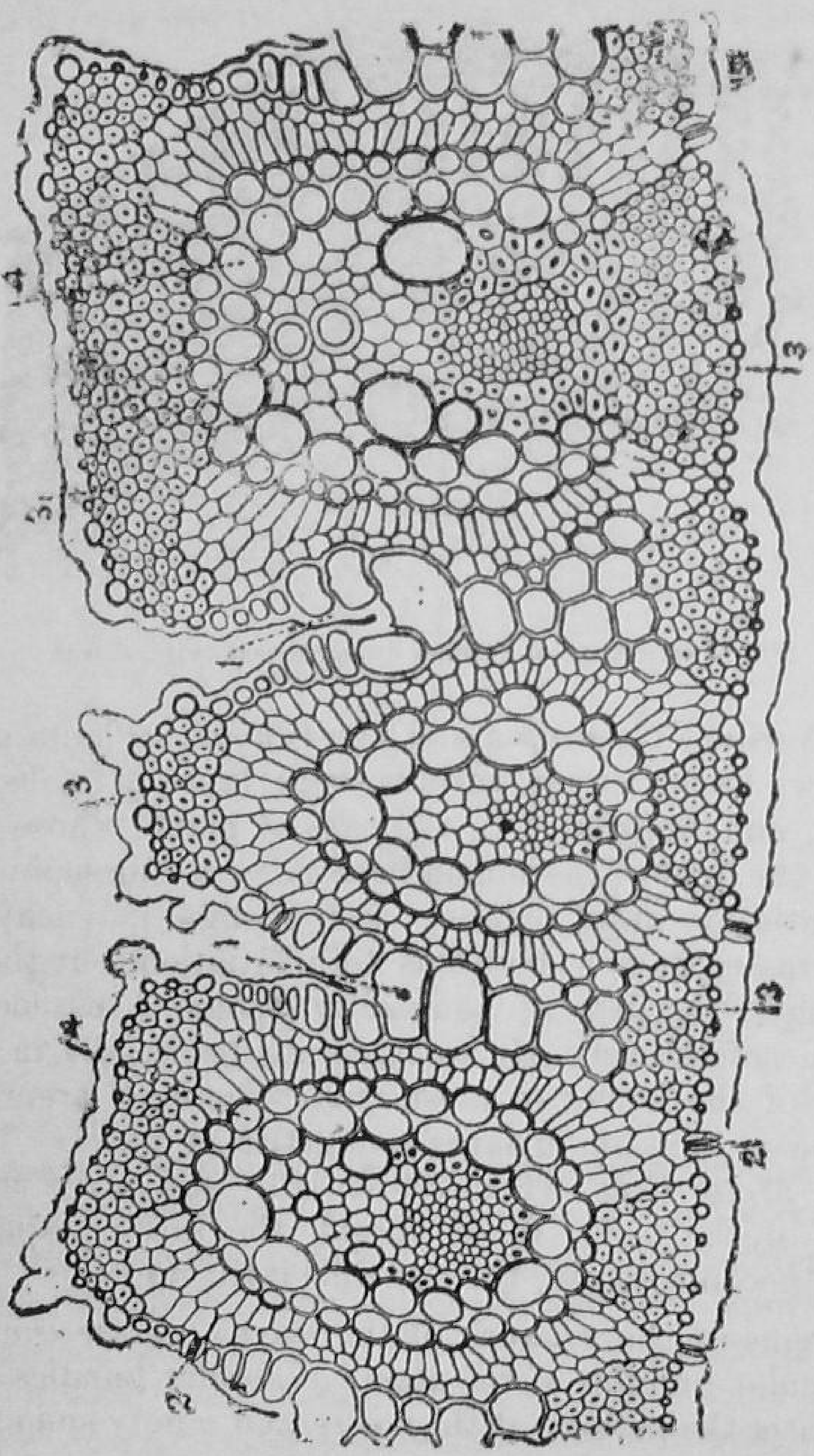


Fig. 209. Transverse section of the leaf of *Aristida setacea* showing the arrangement of sclerenchymatous band ; (1) motor cells (2) stomata (3) sclerenchymatous band (4) bundle sheath.

layer or layers of parenchymatous cells which are elongated and closely set without intercellular spaces. These are sometimes called bundle sheaths (Fig. 209). Strands of sclerenchyma are

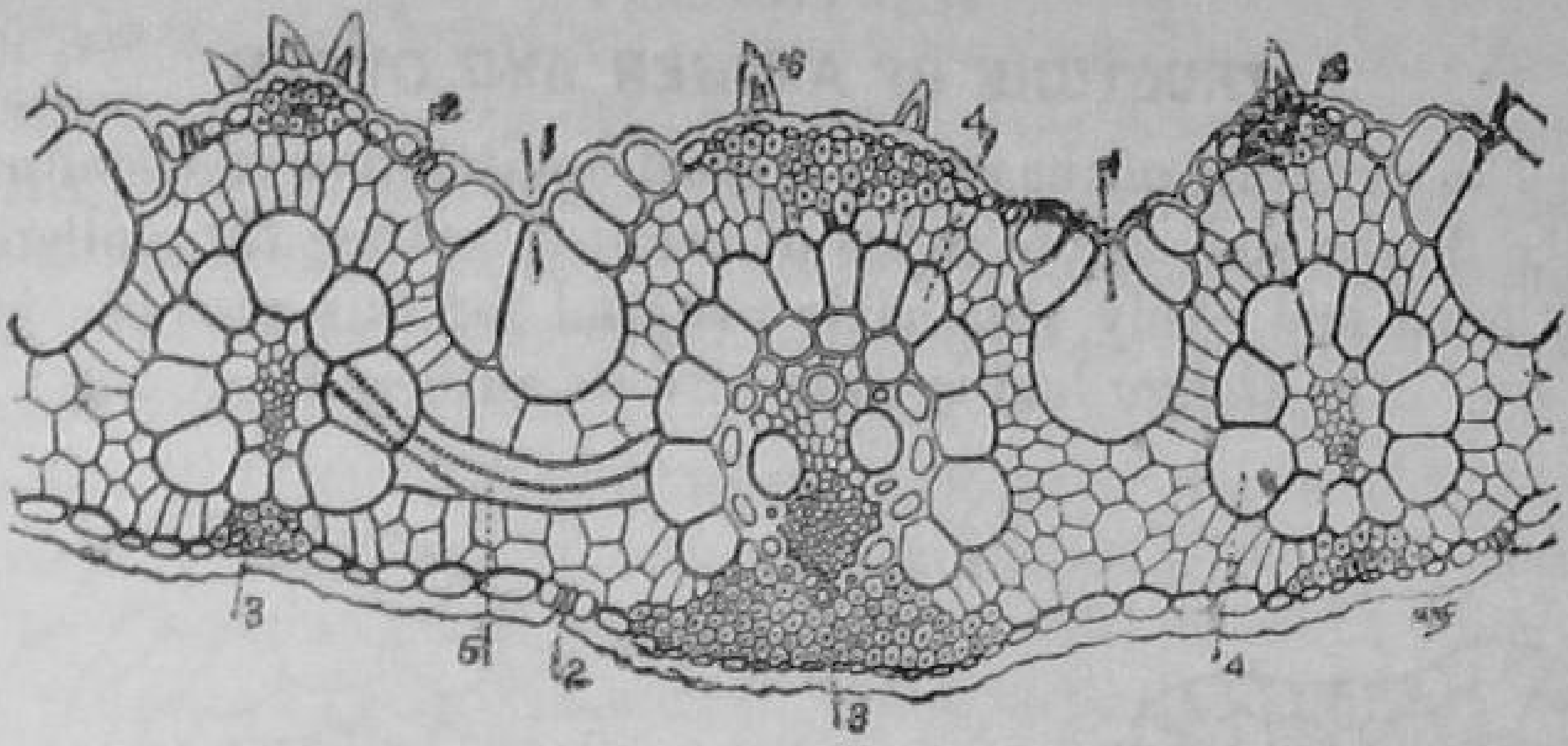


Fig. 210. Transverse section of the leaf of *Eragrostis willdonoviana*. (1) Motor cell ; (2) epidermis ; (3) sclerenchyma ; (4) bundle sheath ; (5) longitudinal section of a vascular bundle.

also found close to the veins either on the lower side close to the phloem, or on both sides of the veins. Leaves of grasses have such bundles of sclerenchyma on both sides, or on one side of the vascular bundles. The margins of leaves are sometimes strengthened with sclerenchyma in many grasses (Fig. 209).

CHAPTER XVI

STRUCTURE OF ANTHER AND OVULE

The structure of the anther is most easily followed if examined in the flower bud, before it has dehisced to release the pollen. A very good and easily obtainable material for this purpose is the *Datura*. The *Datura* bud is large with its anthers fairly big. The

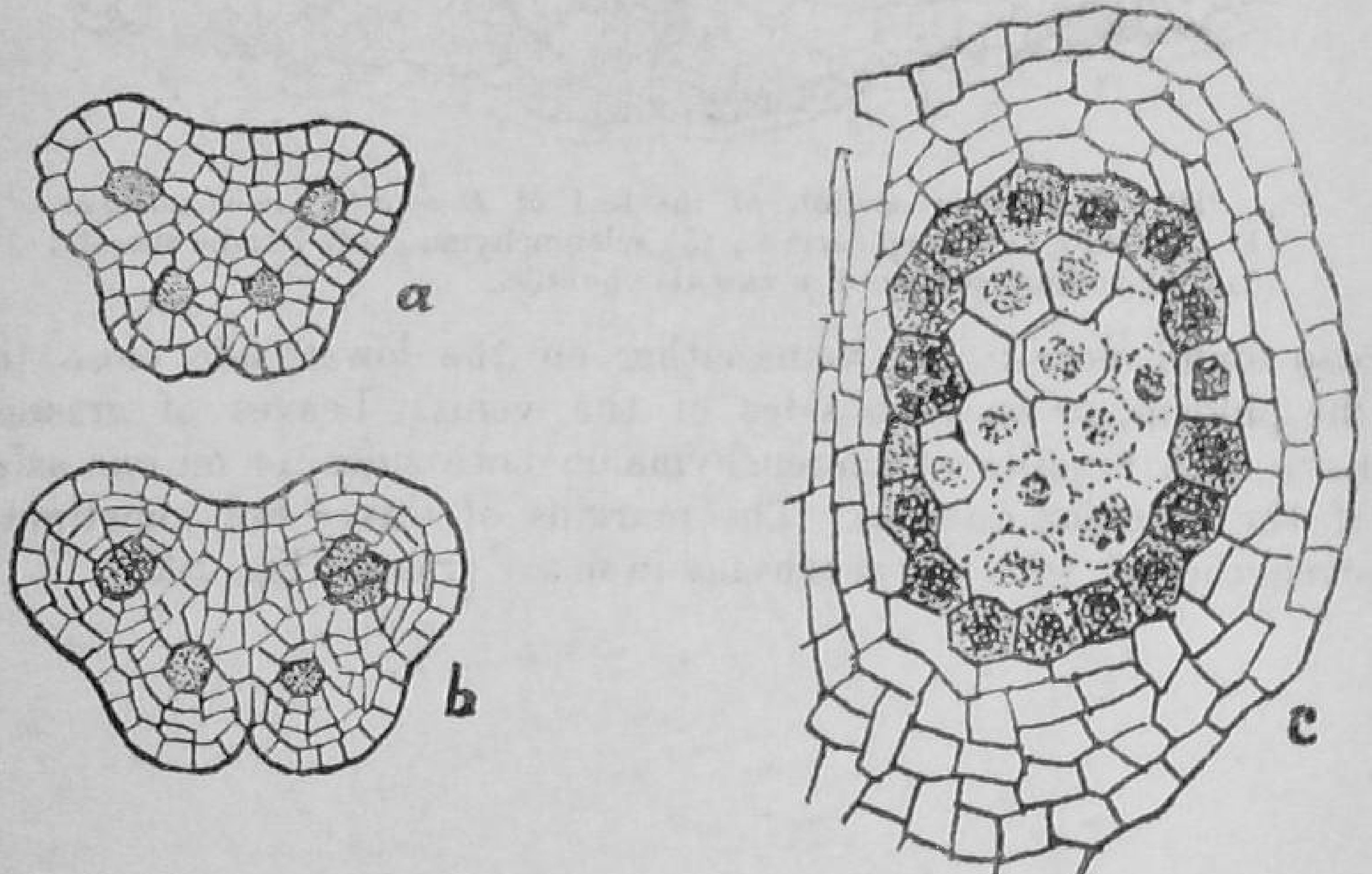


Fig 211. Stages in the development of anther sac (*a* and *b*) initial stages. (*c*): P. M. C. dividing. Note the tapetum with dense protoplasm. V. B.= Vascular bundle ; P=Pollen grains ; F=Fibrous layer"

bud appears tubular and green because of the calyx which encloses all the other parts. When it is dissected it will be noticed that the filament is relatively short while the anther is well developed. There are two anther lobes, each of which has a deep longitudinal groove,

which marks the line between the two pollen sacs contained in each anther lobe. The detailed arrangement and structure is seen clearly in a transverse section of the young anther (Fig. 211-A) A large proportion of the section is seen to consist of parenchymatous cells with protoplasmic contents and conspicuous nuclei. Between the anther lobes lie the tissues of the connective containing a small vascular strand made up of a few xylem and phloem elements. The tissue of each anther lobe is seen to be divided into two circular pollen sacs, the central cells of which stand out very prominently in the section owing to their large size, dense protoplasmic contents, and conspicuous nuclei. These cells are closely packed together and though sunk beneath the surface of the tissue, they are evidently able to grow very actively indeed, and have been able to manufacture protoplasm sufficiently fast to keep pace with their growth and multiplication, whilst the cells around have begun to vacuolate, and contain starch, tissue. These are called the *sporogenous cells* as eventually they give rise to the pollen

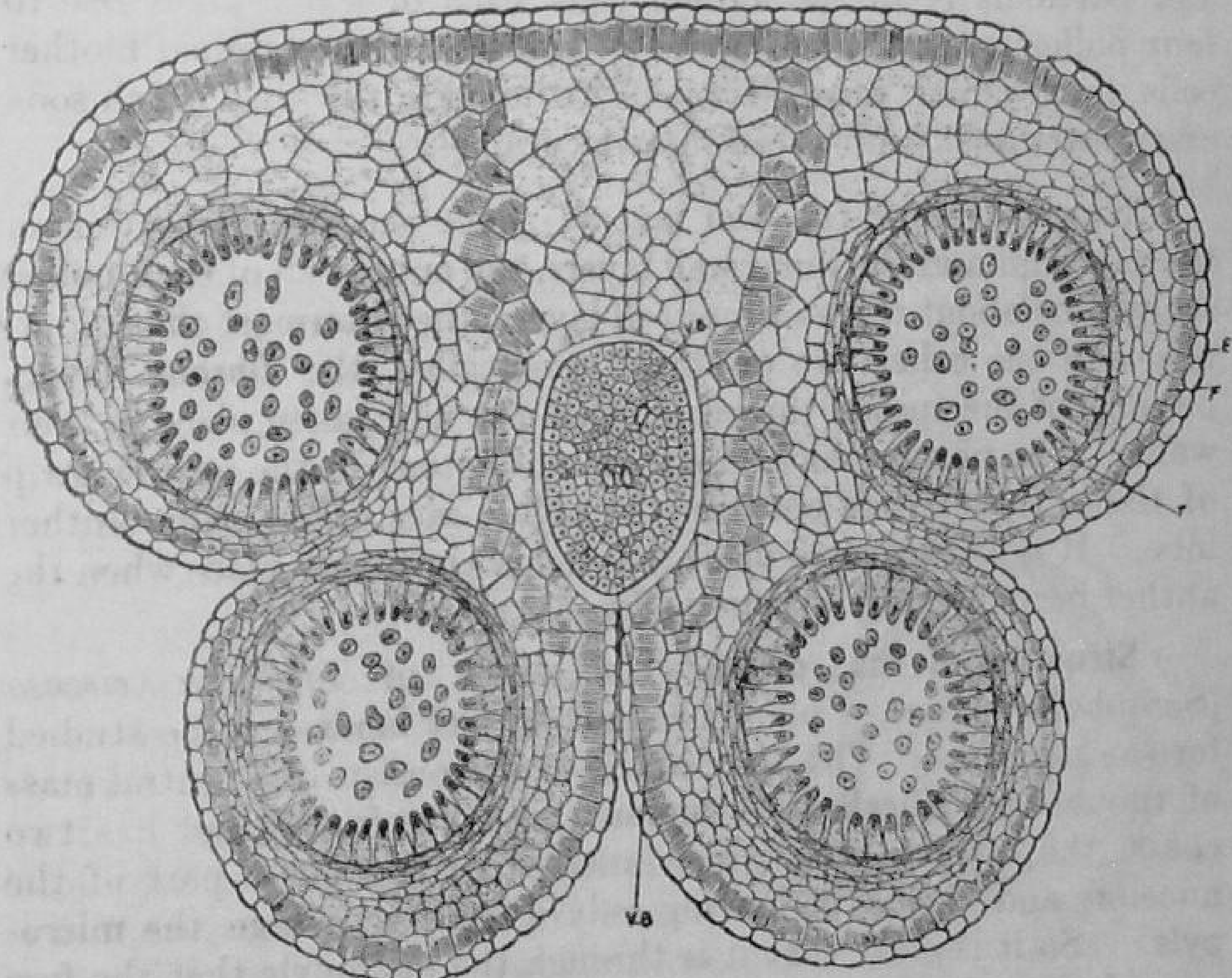


Fig. 211-A. Transverse section through anther. *Note* epidermis, fibrous layer tapetum, vascular bundle and pollen grains.

grains or spores. In the section it will be noticed that the walls of the pollen sacs are composed of several layers of cells. The epidermal cells are relatively flat and in *Datura* there are a few hairs.

The epidermis is followed by four layers of cells which are parenchymatous, containing plenty of protoplasm and starch. Lining the wall of the sac is a very striking layer of cells known as the **tapetum**, the cells of which are closely packed, densely protoplasmic with prominent nuclei.

At this stage the anther undergoes a rapid expansion, which is largely due to the final extension of the cells of the wall, as they complete their vacuolation, and the sporogenous cells then no longer completely fill the cavity of the pollen sac as a densely packed mass, but round off from one another as the **pollen mother cells** (**P.M.C.**) now lying in a liquid medium. These mother cells continue to grow very vigorously, their nuclei undergo characteristic division, *viz.*, reduction division or meiosis, so that there results from each mother cell a group of four cells, a tetrad of pollen grains. During this process the tapetum and the two or three inner wall layers disorganise and their contents are added to the liquid surrounding the developing grains. The rapid growth of the anther and particularly of the mother cells, each of which gives rise to four pollen grains, more or less of the size of the original mother cells, makes great demands upon the liquid in the sacs, which soon disappears as it is absorbed into the grains.

Now to follow the wall layers; since the disorganisation of the tapetum and the inner wall layers, the outer wall of each pollen sac will be about three or four cell layers, the outermost the epidermis, and the other two or three, now called the **fibrous layers** because of the special thickening that has now taken place in their walls. The fibrous thickening does not extend to the narrow strip of tissue that is left between the pollen sacs of the same anther lobe. It is at this weak place that dehiscence takes place when the anther becomes fully matured (Fig. 211-A).

Structure of the ovule.—The ovule of *Stemodia viscosa* (Scrophulariaceae), a plant common in wet lands, can be studied for the structure. The body of the ovule consists of a central mass of tissue—the **Nucellus** continuous with the funicle and has two coats, the **integuments** which arise from the lower part of the nucellus and enclose it leaving only a narrow passage the **micropyle**. So it is clear that it is through the micropyle that the free end of the nucellus could be approached. Each ovule arises as an outgrowth from the placenta. Just below the apex of the nucellus, a single denser sub-epidermal cell divides into two, an upper tapetal cell and an inner and lower **archesporial cell**. The archesporial cell undergoes reduction division as in the case of the sporogenous cells which give rise to the pollen grains. This

division though giving a file instead of a tetrad, regarded as comparable with the division of the pollen mother cells into the four pollen grains, and the parent cell is often described as the **egg mother cell (EMC)** though in this case only one of the resulting cells forms a fertile "spore." This cell grows very large indeed, mainly at the expense of the neighbouring cells, which are disorganised and absorbed during its development. This cell enlarged is known as the **embryo sac** (Fig. 211-B).

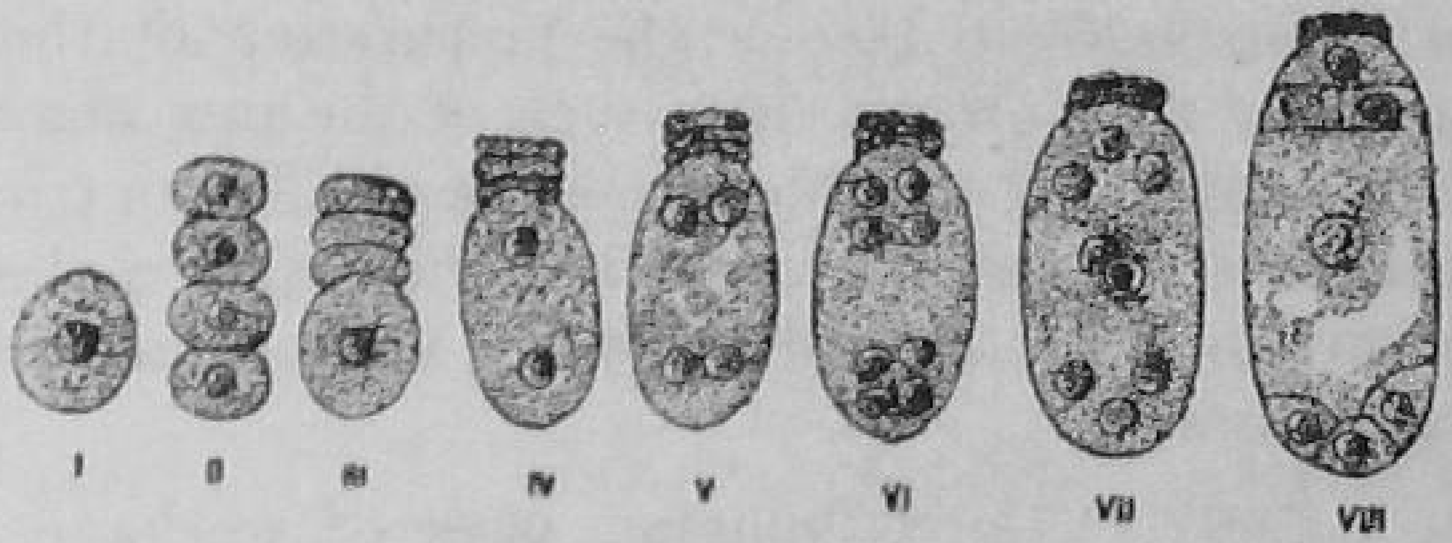


Fig. 211-B. Development of embryo Sac from egg mother cell.

In the meanwhile, the integuments are formed, the inner one first and the outer one later. The funicle is also formed by the growth and division of the cells at the base of the ovule.

As the embryo sac grows it not only absorbs the sister cells, but it even attacks the epidermis of the nucellus which is all soon digested so that only the basal part of the nucellus lying below the embryo sac remains while the side and top of the sac come into contact with the inner integument. The nucleus of the embryo sac now undergoes division three times so that eight nuclei are formed, a group of 4 occupying each end. Three of them come to lie nearer the micropyle, three at the opposite end and two move to the centre. Of the three at the free end, the one innermost, more or less rounded and comparatively large with more cytoplasm round about it is the **ovum or egg cell**, the other two which are rather elongated are called the **synergidae**; the three at the other end, the antipodal cells and the two (derived one from each polar group) now fused into one, the **endosperm nucleus**. At this stage the ovule is ready for fertilization (Fig. 212).

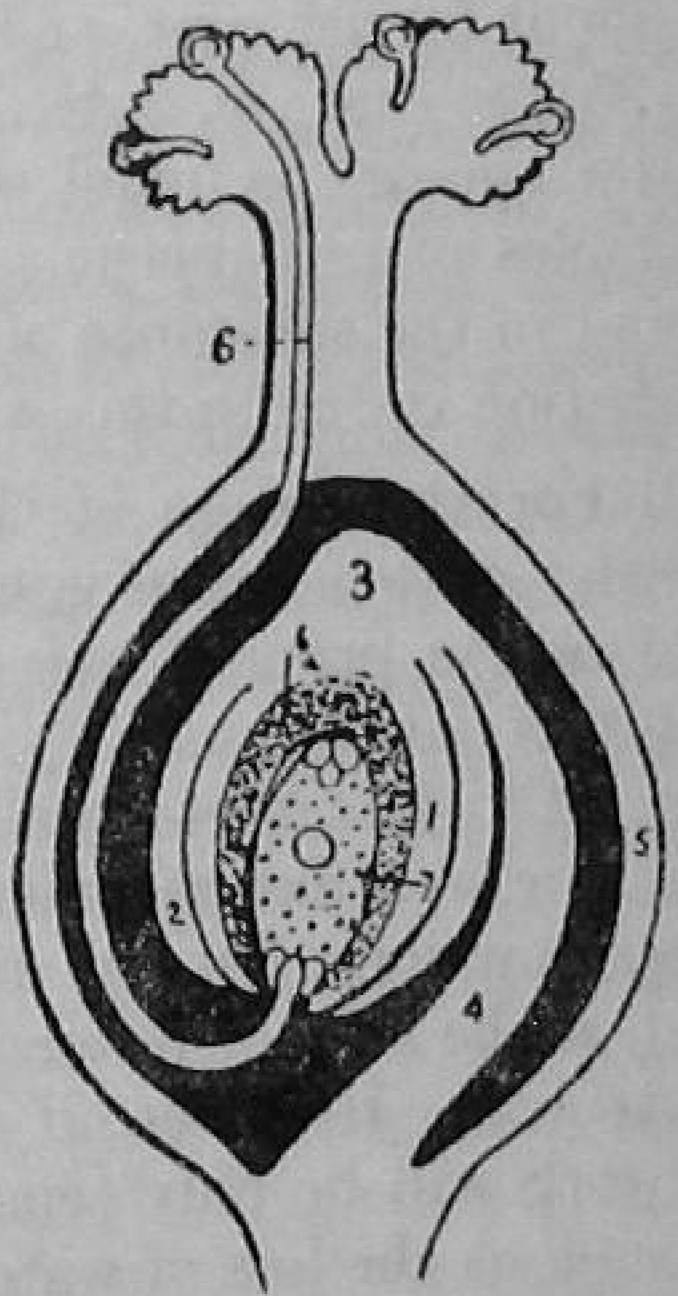


Fig 212. Diagram to illustrate pollination and fertilisation 1 and 2 integuments; 3, chalaza; 4, funicle; 5, perecarp; 6, nucellus; 6, pollen tube; 7, embryo-sac.

PHYSIOLOGY

CHAPTER XVII

SOILS AND MICRO-ORGANISMS

Land plants have to use for the preparation of their food so necessary for their growth, only such of the raw materials as are available in the soil and the atmosphere. The nutrient substances that exist in the soil and which the plants make use of in the preparation of their food are water, certain salts dissolved in water and gases.

From a study of the germination of seeds we have already learnt that water is indispensable for the life of the plant. The very maintenance of the form of the plant when young is entirely dependent upon the presence of water in large quantities. All the chemical changes occurring in plants are carried out only in watery solutions. The protoplasm which is the physical basis of life can be active only when it contains 75 per cent or more of water. The amount of water which a woody plant possesses is about 50 per cent, and a succulent plant may contain as much as 95 per cent of water. In plants a very large portion of the water appears as liquid water in the cavities of vessels and in the vacuoles of protoplasm. Besides this, a fair amount of water is found in the substance of cell walls and protoplasm. The swollen condition is due to this water and it is termed *water of imbibition.*

For the escape of the embryo from the seed coat and its further growth water is essential. All the cells in the cotyledons and in the primary axis become filled with water almost to the point of saturation. By this the living cells become active, and the activity is kept up all through the life of the plant. So long as there is sufficient amount of water in these cells they perform their functions, but any diminution in water affects these functions and, if the loss of water is much, the life of the plant may be destroyed. However, if the diminution is not great, cessation of work will be only temporary and resumption of work follows, as soon as the loss of water is made good.

While aquatics obtain their requirements from the very medium of water in which they live, all the water that a land plant absorbs is taken from the thin films of water, adhering to the soil particles.

The soil has three main uses in the plant's economy : firstly it provides a firm anchorage and support whereby the plant may be held strongly in position ; secondly, it furnishes the supply of water which the plant uses and thirdly and most important is that it contributes certain mineral salts essential to the plant's successful growth and development.

Soils vary much in physical texture, chemical composition, depth, origin, richness and other respects but all normally are made up of a mixture of distinct components, each of which has its own influence upon the life of plants. The soil components are (1) rock particles, (2) water, (3) air, (4) organic matter, (5) dissolved substances and (6) organisms.

1. Rock Particles

The great portion and the basic material of a soil is composed of small angular particles which are derived by disintegration of rock. These make up 90 per cent of the soil and are responsible for all the benefits already stated. The particles vary greatly in size from those of very fine clay to those of coarse gravel and it is chiefly on the basis of particle size that soils are classified into such types as clay, loam, sandy loam, etc. Soil particles may be formed by the weathering and breaking up of the rock masses directly below them or they may be formed by the grinding up or erosion of rock through the action of rain or ice and may often be transported long distances from their point of origin as in the case of soils of flood plains or sand drifted and carried by high winds. The differences in the particle size and chemical composition depend on the type of rock from which the respective particles are produced. Since soil particles are very irregular in form they do not fit very closely together and the result is, there is a considerable amount of space (**pore space**) between them. The pore spaces are occupied either by water or air. In soils which are ideal for the growth of plants the particles cohere in groups to form *floccules or crumbs*, the component grains of which are held together by water films or by such a cementing substance as clay. Tillage which is an important agricultural operation does this for the soil and that is it imparts this *crumb* structure or *flocculation* to a soil. At the soil surface, by the direct action of rain or by other means, these crumbs may be broken into their constituent particles which then pack closely together and on drying form into a firm clay like crust.

2. Soil Water

Water plays no small part in the life of plants. Its importance can never be exaggerated. The bulk of the weight of a plant is

water; it enters into the manufacture of food; it is responsible for the maintenance of the turgidity of the tissues and in its capacity as a solvent it serves as a general medium in which most physiological processes are carried on. If one takes into consideration the sources for the supply of this vital substance, first and foremost stands rain. The amount of rainfall determines to a very great extent the character of the vegetation of any place. In India where we have the monsoon rains, one is struck with the luxuriant vegetation of the places which get the full benefit of the monsoon whichever it is, south-west or north-east and one is equally struck with the barrenness of vegetation in places on which the monsoons have practically no effect. In Southern India there are the tropical rain forests of the Western Ghats on the one hand and the dry as dust desert regions in the central Districts of the Deccan plateau. It has been found that for ordinary agricultural practice a fall of about 40 inches a year, evenly distributed through the seasons, is most favourable.

A considerable portion of the water that is obtained through rain may not enter the soil at all if the surface is hard or the rainfall heavy but may drain away instead. This **run off** is lost to plants and may even do much harm by washing away a portion of the soil itself and it is against the **soil erosion** as it is called, which is a great loss to the agriculturists that various precautions are taken such as **bunding,** growing of the soil binders, etc. The water that enters the soil either may **percolate** downward between the particles under the influence of gravity or may be held in the soil by **capillarity.** Percolating or gravitational water passes downward rapidly if the soil particles are coarse, more slowly if they are finer, until it arrives at a level where all the soil spaces are filled with standing or hydrostatic water. This level is known as the **water table.** Its position at any given point determines the height at which water will stand in a well dug there and its distance below the surface varies from place to place and is subject to much fluctuation. A similar saturated condition occurs in the upper soil layers after heavy rains but persists there only for a short time (the amount of time may slightly vary according to the nature of the soil). When water has percolated downwards to this level it often is beyond the reach of roots and is thus unavailable to plants.

Capillarity Water is water held in the soil by the force of capillarity. A great amount of water is held by the force and attraction between the surface of soil particle and the water in the soil. Water held in this fashion does not therefore percolate and the finer the soil the greater the amount of water that will

be held in this fashion. Each particle in a moist soil is covered by a thin layer of water. The films about adjacent particles coalesce, filling the minuter spaces and lining those that are larger and a continuous film system is thus set up. It is this **film** or capillary water which furnishes plants with the great bulk of their water supply. Rain by itself will not much benefit the agriculturists unless the soil holds the water for some time for use by the crop plants. This quality of the soil is termed **waterholding capacity.** The waterholding capacity of the soil is determined by soil texture and the capillaries between the soil particles. Water moves from wet regions of soil to dry regions by **surface tension, capillarity adsorption** and **imbibition.** In agricultural practice it is very important that one manipulates the soil in such a way that by one means or other its **waterholding capacity** is increased and the waste through run-off or percolation is considerably prevented.

In most soils there is capillary movement of water toward the soil surface where it evaporates. An important purpose of tillage is to prevent waste of water through capillary ascent by breaking up the capillary system at the surface and forming there a layer of loose coarse material called a *mulch*.

Capillary movement is by no means always vertical but may take place in all directions within a soil, just as ink spreads in all directions in a piece of blotting paper. This movement has a tendency to continue until the water films are of equal thickness throughout the entire soil mass, causing it to be uniformly moist. When water is removed at any particular point, say by surface evaporation or root absorption, water will rush up to the spot from all other points until equilibrium is established.

3. Air

It has been recognized that oxygen is very essential for the healthy growth of ordinary plant roots and as such the presence in the soil of an abundant supply of air is a matter of vital importance. Where the spaces of the soil particles become filled with water, most of the air is necessarily driven out and when this condition of saturation is long maintained ordinary plants suffer just as animals suffer from suffocation or asphyxiation in the absence of air. This is what is known as **water logging** which is greatly injurious to all normal plant life. But rarely does this condition exist. Usually excess of water normally passes downward by percolation and as it does so, the soil spaces again fill with air. The soil then is said to be well drained. In most

of our cultivated soils from 20 to 35 per cent of the volume consists of air spaces. The object of ploughing is indeed to loosen the soil and encourage the free play of air. When such an ideal condition results, the soil is said to be in good tilth. Where water is available only in capillary form much air is present in the larger spaces and such a state of the soil is therefore clearly the most ideal for plant growth in that there is then obtainable a plentiful supply of water combined with a plentiful supply of oxygen. The oxygen of soil is partly in gaseous state and partly in dissolved form, and land plants utilise oxygen in both the forms while aquatic plants depend upon the dissolved oxygen. In the case of plants in swamps where there is not sufficient dissolved oxygen, the plants resort to special devices by bearing breathing roots or pneumatophores as in *Avicenia officinnalis.* Aquatic plants develop large intercellular spaces to store air in their body. The tissue with such air spaces is termed **aerenchyma.**

4. Organic Matter

All rich soils such as those of the evergreen tropical forests contain a considerable amount of material derived from the dead bodies of organisms, particularly of plants. Roots which die and remain in the soil and leaves and other plant parts which fall on the soil surface are the sources from which this organic matter is mainly derived in nature. In the practice of scientific agriculture it is increased in amount by the application of manure, the ploughing under of leguminous green manure crops such as Sunnhemp (*Crotalaria juncea*), Dhaincha (*Sesbania aculeata*), Pillipesara (*Phaseolus trilobus*), Kolinji (*Tephrosia purpurea*) and the leaves and stems of other wild plants such as *Calotropis gigantea*, *Pongamia glabra*, *Azadirachta indica*, *Cassia auriculata*, *Gliricidia maculata.* After entering the soil the organic plant matter begins to undergo decomposition and for the most part is broken down finally into simple end products as carbon dioxide, water and ammonia. As this organic material decays, it becomes characteristically dark in colour and undergoes a series of complex chemical changes in which condition it is known as **humus.**

Organic matter is of importance to plant life in many ways. It improves the physical condition of the soil, for, because of its coarser particles the air contents of the soil is increased. Since organic matter absorbs water rapidly, the water holding capacity of the soil is improved. The decomposition of humus liberates certain nutrient materials particularly an abundant supply of

nitrogen compounds which ultimately become available to plants. Above all things, organic material is also the seat and food of the soil bacteria which are indispensable in plant nutrition. Therefore it is that agriculturists are advised to grow green manure crops and enrich their soils thereby with organic matter. This will mean the productivity of the soil is thereby increased and where it is not done the soil gets easily impoverished.

5. Dissolved Substances

The root hairs of plants come into close contact with the soil particles. These particles as already pointed out hold moisture between themselves. The plant absorbs this water through the root hairs. In absorbing the water, the salts that are dissolved in the soil water also enter the root hairs. Neither all the salts nor the basic or acidic radicles of a salt are absorbed in entirely but the living protoplasm of the root hair has the power to choose its requirements. Certain salts, though not directly useful to the plant, may also enter the plant. This **semi-permeability** of the protoplasm is dealt with in detail in a later section. In addition to the salts, dissolved oxygen of water is also absorbed by the plant through the roots.

6. Organisms

It was stated in the beginning that the soil is rich in organisms. Insects which play a great part in nature, worms and rodents, all modify the physical character of the soil by their abode there. Of greater importance than these are those minute and lowly of living things which are grouped together as **micro-organisms.** It is now recognized that without the presence of these micro-organisms the soil would soon become unfit to support a vegetation of higher plants. First and foremost among them are the bacteria, tiny, single celled plants which lack chlorophyll. Many of these (the bacteria of decay) decompose the complex organic substances found in humus into such simple end products as carbon dioxide, water and ammonia, thereby releasing great quantities of nutrient materials, which would otherwise be locked up and remain useless in the dead bodies of animals and plants. There are bacteria which are responsible for the continual circulation of nitrogen through its various successive stations in organisms, air and soil (**the nitrogen cycle** as it is called). Complex nitrogenous substances returned to the soil in the bodies of dead animals and plants are worked upon by the bacteria of decay into simpler compounds which are finally reduced to ammonia. It has to be

remembered at this stage that most plants can use nitrogen only when it occurs in the form of nitrate salts (such as potassium nitrate, KNO_3) and therefore the ammonia made available in the soil by the action of the bacteria of decay must first be converted into nitrates through the process of **nitrification.** This is carried on by two types of nitrifying bacteria; the nitrite bacteria (*Nitrosomanas*) which change ammonia into nitrites (NO_2 Compounds) and the nitrate bacteria (*Nitrobacter*) which in turn convert nitrites into nitrates (NO_3, compounds). In this form, nitrogen is already absorbed and assimilated by plants and ultimately returned to the soil again through the bodies of plants or animals, thus completing the cycle. Some plants, such as rice, may use nitrogen in the form of ammonia compounds and for their nutrition the activity of nitrifying bacteria is thus unnecessary.

When the process of decay and decomposition go on in the soil due to the activity of the **denitrifying** bacteria it has to be borne in mind that by no means all of the nitrogen in dead organic matter is ultimately made available to the roots of plants, for ammonia is decomposed and its nitrogen is liberated into the air in gaseous form. The atmosphere, over 80 per cent of which consists of nitrogen, evidently constitutes a vast reserve supply of this element, but unfortunately in this form it is absolutely unavailable to most plants. One of the wonders of nature, as we might put it, is that there are small group of bacteria however, which have the fortunate ability to absorb gaseous nitrogen and to build it into more complex compounds in their bodies. These are the **nitrogen fixing** bacteria. They are present in almost all soils and cause the development of the tubercles or nodules usually found on the roots of plants belonging to the legume family which includes, the pulses, groundnut, the several common green manure crops already considered under humus formation, and the fodder plant such as lucerne. This nitrogenous supply ultimately becomes available to the particular plant on the roots of which the bacteria grow. Experiment has proved that a leguminous plant is able to acquire an abundant supply of nitrogen through the aid of these bacteria even in a soil which is not originally supplied with nitrates. The relationship between the legume and the bacteria is termed **symbiosis.** The knowledge is of great significance in modern agriculture. Hence it is that among green manure crops, leguminous ones are the best to grow and hence it is that in a rotation of crops, a leguminous crop, be it a pulse like a blackgram or redgram or an oilseed like groundnut, finds an important place. Nitrogen fixing bacteria are also found in

nodules on the roots of a few other plants like *Cycads* and *Alders* and in the leaves of some rubiaceous plants such as *Pavetta* and *Psychotria*. In the case of the rubiaceous plants the most interesting fact is that the bacteria are present in the seeds and are thus handed on to the next generation.

There are certain bacterial types, notably species of the genera *Azotobacter* and *Clostridium* which live freely in the soil and are not associated with any other plant and these are also able to absorb gaseous nitrogen and to build it into complex organic substances, and these micro-organisms are therefore of very great importance in increasing the supply of available nitrogen in the soil.

In the case of many species of plants particularly those which grow in forests or other places rich in humus (*Orchidaceae, Ericaceae, Liliaceae, etc.*) thread like filaments of fungi are intimately associated with the smaller roots entering their outer tissues and surrounding the root with a web like jacket of fungus threads. This **root–fungus** association is known as a **mycorrhiza.** There are two types of mycorrhiza. In the **endotrophic mycorrhiza** as found in black maple (*Acer nigrum*), Walnut (*Juglans regia*), etc., the fungal filaments penetrate the cortex of the root and enter the cells curling up inside. In the **ectotrophic mycorrhiza** of the birch (*Betula*), beech (*Fagus*), Oak (*Quercus*), etc., the hyphae cover only the surface of the roots and do not penetrate into the interior. The fungus takes the places of the root hairs and aids the plant in absorbing water and nutrient material from the soil and gets in return organic food (sugars and starch) from the plant.

Acidity.—The acidity of the soil is of much importance to plants. Degree of acidity is determined by the character of the rock particles and by the chemical changes going on in the soil. There are plants like the *Rhododendrons* which require relatively an acid soil, while most crop plants require a rather alkaline soil. The application of lime is the commonest means for correcting too great soil acidity. Lime thus plays an important part in altering the condition of the soil.

Soil science is still complex and a precise knowledge of many of its aspects is still lacking. Human beings depend on agriculture for food and many other requirements and this is more true of India than of any other country where the bulk of the population is made up of cultivators. The knowledge obtained so far in regard to soil is being made use of in all countries where cultivation is on modern scientific lines.

CHAPTER XVIII

ABSORPTION AND MOVEMENT OF WATER

The part of the plant which takes up water from the soil is the root system, but the parts directly concerned in this work, are, however, the root hairs, clothing the young parts of roots just close to the root tips. (Figs. 213 and 214). Where root hairs are not developed, which is the case in most aquatic plants, the function of absorption is carried on by the epidermal cells found near the root tip. Root hairs are merely the cylindrical protrusions of the epidermal cells and they cause an increase in the area of the surface for absorption. In a pea plant the formation of root hairs is said to increase the surface of absorption twelvefold.

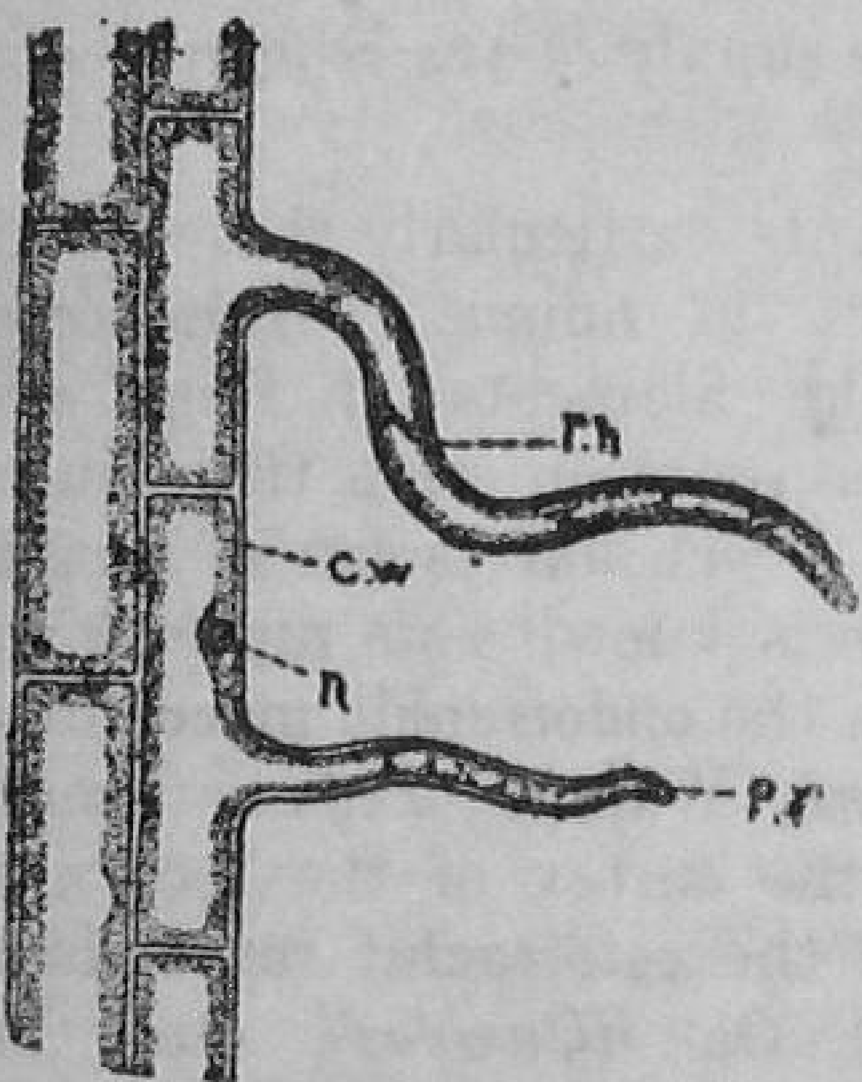


Fig. 213. Root hairs highly magnified. r.h.=root hair; c.w.=cell wall; n=nucleus; pr=proto plasm.

Since the amount of water that a plant needs is very considerable, there should always be a large number of root hairs in a plant. It is true that root hairs are ephemeral structures inasmuch as the life of a root hair is a matter of a day or two. But every root of a plant bears root hairs throughout its life, and the root hair region in a growing root would be found to be more or less constant in its extent although its position is found to be advancing forward with the growth of the root tip. Just behind the elongating region new root hairs are formed to replace those that are shrivelling and dying behind. In other words, every day as many root hairs are formed in front of the root hair region as wither up behind this region. In addition roots produce lateral branches, thus leading to the increase in the number of root hairs.

A root hair being a cell containing protoplasm, absorption of water must be its essential feature. It consists of a cell wall of cellulose enclosing protoplasm containing vacuoles. Every root hair grows in between the soil particles and becomes attached to them. So, between the film of water adhering to the soil particle

and the water in the vacuole of the protoplasm, there is a distinct membrane consisting of the cell wall and the protoplasm. The condition of the cell sap and the forces at work are such that water goes into the interior of the root hair, but water does not get out from inside the root hair.

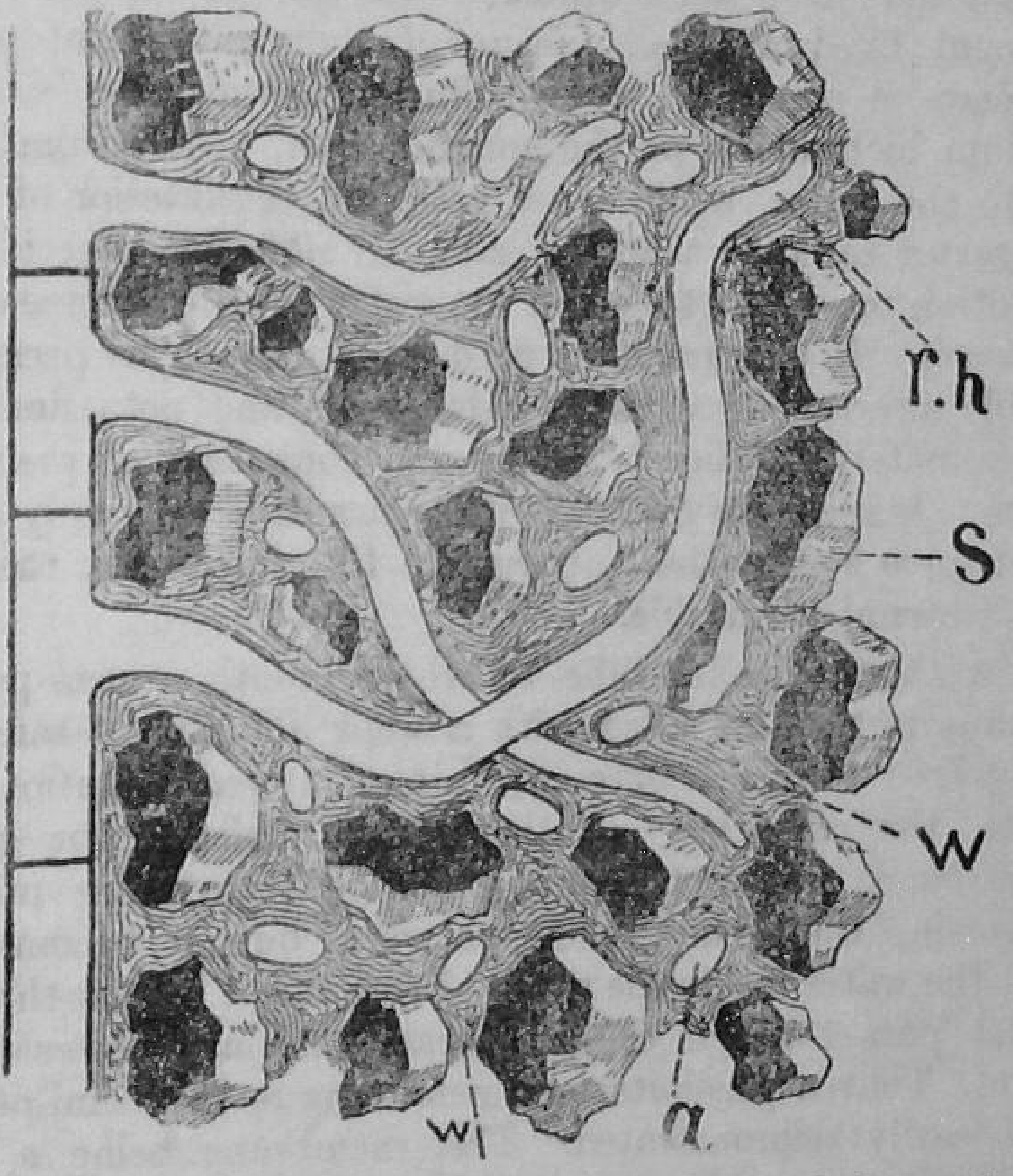


Fig. 214. Root hairs and soil partcles; r.h=root hair; s=soil particle; w=water; a=air space.

Semi-Permeable Membrane

The root hairs are in close contact with soil water. The root hair acts as a gateway for the entrance of soil water into the plant. There are certain outstanding physical forces which operate to enable the water and certain salts in solution to enter the root hair without the reverse action taking place. For a clear grasp of how this one-sided passage of water is brought about in a plant it is necessary to understand the behaviour of solutions in water, with reference to one another and also to membranes they come in contact with. When two solutions of unequal density are brought together, diffusion takes place slowly. For instance, into a tall jar filled with water, if a solution of potassium bichromate is poured through a thistle funnel tube so as to form a layer

at the bottom and left to itself, the bichromate of potassium will diffuse into the water slowly and this process will go on, until the whole of the water becomes uniformly yellow. If, instead of bringing together the surfaces of water and potassium bichromate directly into contact, a membrane, such as a piece of parchment, is interposed, even then diffusion will go on. When a tube of parchment filled with a solution of common salt of potassium bichromate is placed in water diffusion commences. The solute, potassium bichromate or the common salt, passes from the tube out into the water, while water gets into the interior of the tube with greater rapidity than the salt. If sufficient time is allowed, the solution inside the tube and the water outside become equalised in strength. If parchment is used, it appears to be permeable to diffusible substances, such as salt, sugar and potassium nitrate indiscriminately. When a membrane consisting of precipitation membrane is used, we find that it is permeable fully only to water, but not so to every other substance. In other words, these membranes are **semi-permeable.**

If a thistle funnel tube to whose mouth a semi-permeable membrane is tied, be filled with a weak solution of tannin and, then lowered into a beaker containing a weak solution of iron sulphate, the colourless solution in the thistle tube gradually becomes black, whilst the liquid in the beaker remains quite clear. On reversing the arrangement the water outside becomes black, but not the water inside the tube. From this it is clear that tannin does not pass through the membrane although water and iron salts do. That a precipitation membrane is also semi-permeable can be easily demonstrated. This membrane being a delicate one it must have a support. Prepare two tubes of parchment and fill both the tubes with a weak solution (1 per cent) of calcium nitrate. Immerse one tube in pure water and the other in a weak solution of disodic-phosphate. Add a little methylene blue to the liquid within the tubes. After a day methylene blue is seen in the water, but not in the solution of disodic-phosphate. This is because a precipitation membrane of calcium phosphate is formed close to the parchment inside the tube, which is impermeable to a solution of methylene blue. By using potassium ferrocyanide and copper sulphate solutions, a membrane of ferro cyanide of copper is formed which is also semi-permeable.

In the case of root hairs, and for that matter all living cells also, the cellulose cell wall is permeable to water and salts, but the protoplasm layer behaves as a semi-permeable membrane. This can be demonstrated, by immersing bits of tissues whose cells have coloured cell sap in solution of potassium nitrate, varying

in strength from 3 to 5 per cent. Staminal hairs of *Cyanotis*, bits of beet root or scrapings from blue, violet, or red petals serve this purpose very well. When any one of these is placed in salt or potassium nitrate solution, certain changes are observed in the cells. As soon as the salt solution passes into the cell, the protoplasm shrinks to a slight extent at first, leaving some space between it and the cell wall. This phenomenon is termed *plasmolysis*. This space increases gradually and the protoplasm shrinks more and more. The coloured sap is confined to the vacuole within the protoplasm. Since fluids are incompressible it follows that the addition of salt solution has caused some of the water of the cell sap to pass out from the vacuole, but none of the dissolved pigment to which the cell sap owes its colour has escaped from the vacuole. Thus it is clear that the cell wall is permeable, whilst the protoplasmic membrane is semi-permeable. The passage of water outwards from within the vacuole, through the protoplasmic layer, is caused by the salt in the water outside. The presence of the solutes in the cell sap of cells will also cause water to move into the cell sap contained in the vacuole through the protoplasm. Of course some of the salts dissolevd in water may also pass in through the protoplasmic layer.

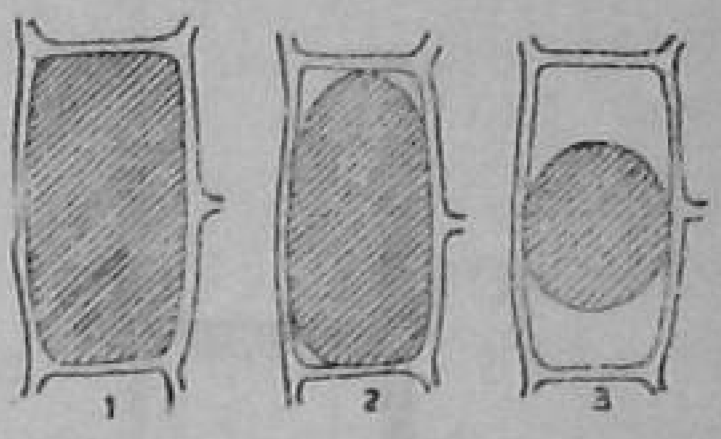


Fig. 215. Plasmolysisof a cell.

Osmosis :—Within the living cells of plants are formed various solutes among which sugars are prominent, and to which the protoplasmic membranes bounding the vacuoles appear to be practically impermeable. These solutes are known as **osmotic** substances. The processes of absorption and movement of water within the plant depend on the passage of water through membranes on the other side of which solutes exist, in accordance with the universal tendency to establish equilibrium.

Just like other cells, root hairs contain in their cell sap solutes which are osmotic. The osmotic pressure of cell sap increases with its concentration. Water in the soil must pass through the cell wall and the protoplasmic layer of the root hair and get into the vacuole on account of the presence of solutes in the cell sap. This process of the passage of a solvent through a semi-permeable membrane which will not allow the solute to pass out is called **osmosis.** As water gets into the root-hair, a certain amount of pressure is exerted on the wall of the membrane and this pressure makes the root hair turgid and this is termed turgor pressure. The turgor pressure developed by osmosis depends upon the degree

of permeability of the membrane that separates the two solutions. For solutions of some osmotic pressure, different turgor would result by use of different membranes such as parchment or animal bladder. It is therefore to be distinguished that the **turgor represents the actual pressure developed** by the entrance of water into a cell by osmosis while **osmotic pressure is a rating of the solution.**

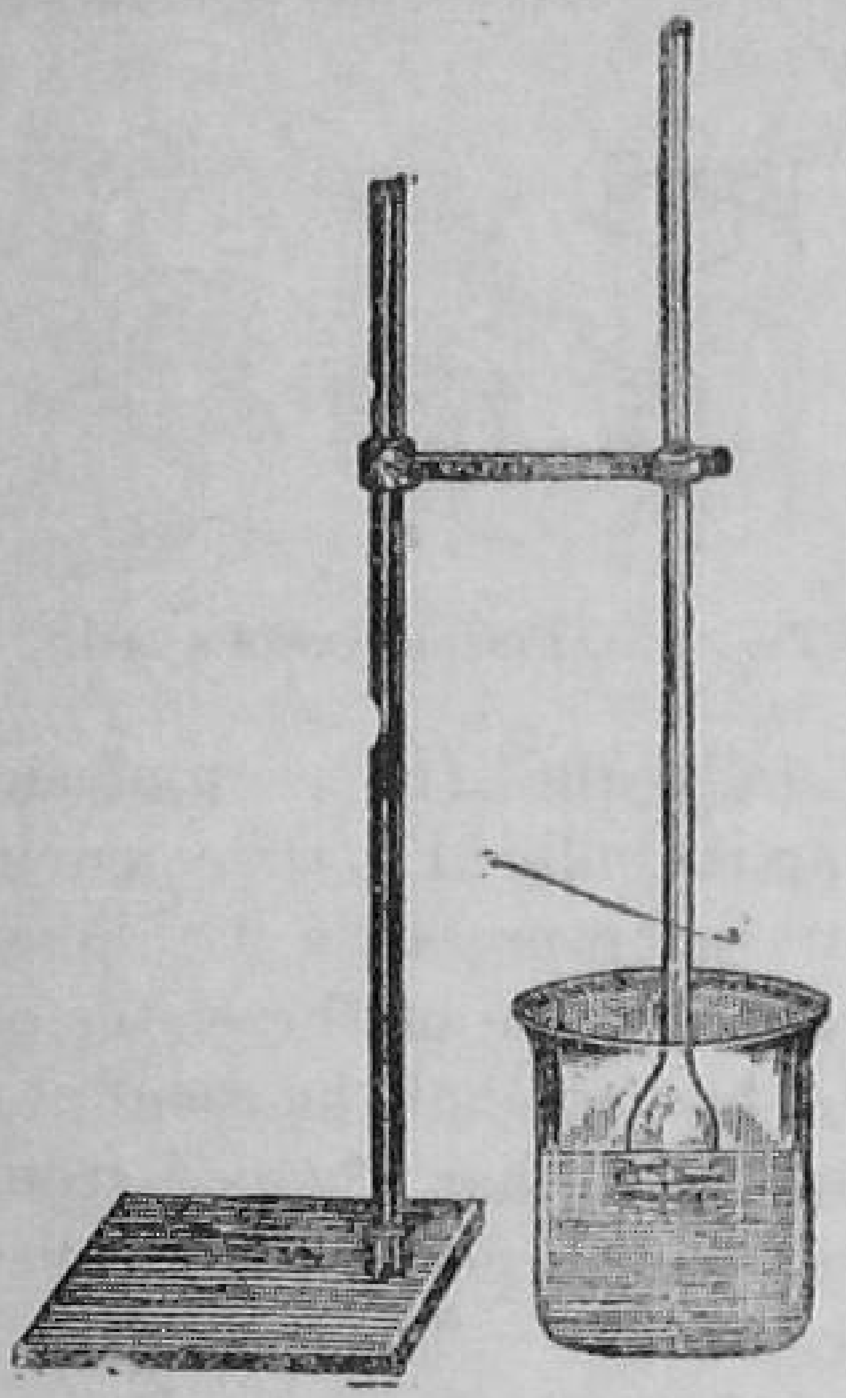


Fig. 216. An experiment to explain Osmosis. Note the semi-permeale membrame that separates the liquid in the funnel.

Now we are in a position to realise the importance to the plant of this property of semi-permeability of the layer of protoplasm enclosing the vacuole. If the protoplasm were to be as permeable as cell wall to all the substances, there would be a constant osmotic leakage of osmotic substances from the root hairs and cells of plants into the soil and absorption of water would not be possible.

The soil water in which various salts are in solution passes into the root hairs, because of the presence of osmotically active substances within the protoplasmic film. The water thus absorbed from the soil by the root hairs passes slowly from cell to cell into the cortex, which serves the young root as a temporary reservoir. The passage of water from the root hair into the adjoining parenchymatous cells of the cortex is in accordance with the ordinary laws of osmosis. As absorption is going on continuously, all the cells of the cortex become turgid and the internal pressure becomes great.

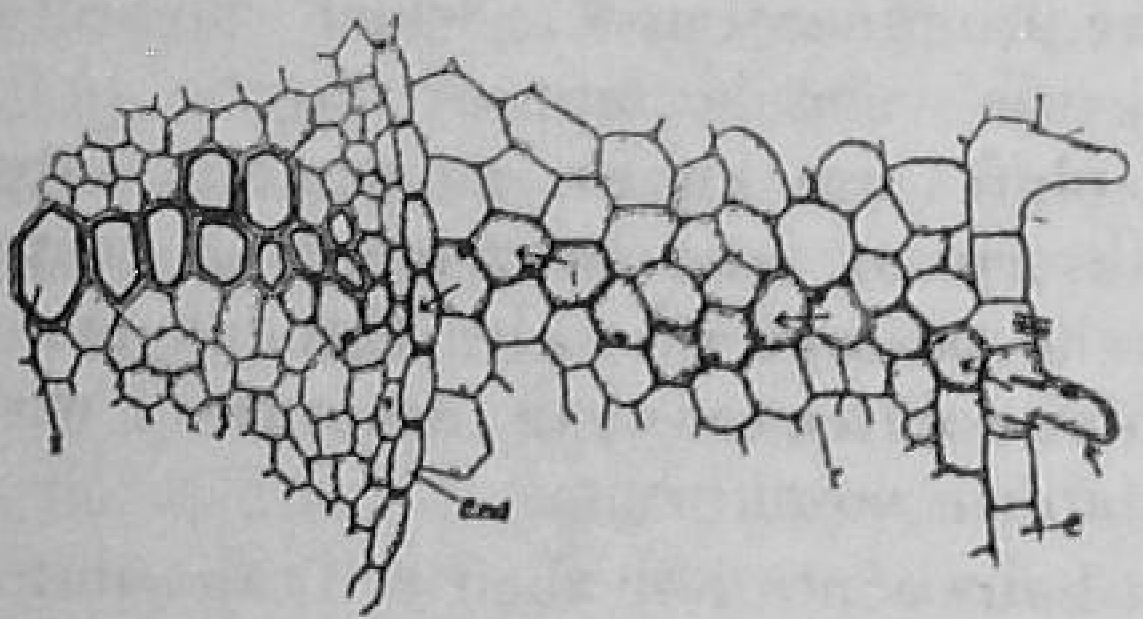


Fig. 217. Diagrammatic representation of the passage of soil water from root hair to the vessels.

Movement of Water in Root and Stem

The endodermis appears to be of great use in facilitating the passage of water from the cortex into the stele by preventing water

from passing laterally. This layer is particularly well developed in roots and the suberisation of the lateral walls of the cells renders these walls impervious to water.

The water passing into the stele under the control of the protoplasm gets into the vessels and tracheids of the xylem. The movement of water through the conducting tissue of the plant is very rapid. Water passes from xylem of the root to the xylem of the stem, as the xylems of both are continuous. From the stem, water finds its way into the leaves through the veins. Almost all the water that is absorbed by the roots passes into the leaves. Of all the organs of the plant it is the leaf that needs water in large quantities. The fine net work of veins, besides forming a very efficient framework to keep in position the mesophyll cell of the leaf, is also useful in carrying water to every nook and corner of the leaf, so that all the cells of the mesophyll may draw water. Further the cells of the bundle sheaths connected with the veins take in the water from the veins very readily to deliver it to the palisade and spongy parenchyma. They are also useful in helping the transfer of food materials from parenchyma to sieve tubes.

That water passes in the stem and the leaves only through the xylem, can be easily demonstrated. Place a fairly well developed seedling of any plant or leafy branches in water, coloured red with eosin, and after an hour or two examine transverse longitudinal sections of the stem and the root. In the stem the xylem alone will be red, whereas in the root all the parts, roots hairs, cortex and the xylem will be stained red.

In the stem the xylem region through which water passes is nearer the periphery. This is the case even in stout branches in which a considerable amount of wood is present, because water passes only through recently formed xylem, and not through old wood. So there is the danger of some of this water moving through the xylem being lost by evaporation. But this is very effectively prevented in all young stems by the epidermis. In the roots the exodermis and the endodermis are also useful in this connection. As more water passes through the xylem of older stems and as the epidermis becomes torn, more effective protection is required and, therefore, we find cork in older stems taking the place of the epidermis. Besides forming a very efficient water proof covering, cork affords protection against the bad effects that may result when sudden changes of temperature occur, because it is a very bad conductor. The importance of cork as a water proofing material can be realised by the fact that a potato deprived of its corky

covering loses in two days sixty times as much water as an unpeeled one of equal weight.

The conducting tissue or xylem which the water absorbed by the root hairs has to traverse in a small plant is not very extensive in length ; but in the case of tall trees the transpiration stream or the water ascending in the xylem has to pass through a very long stretch of xylem to reach the leaves. In nature we see the transpiration stream reaching the leaves in trees which are as tall as 200 or 300 feet.

It has been shown that the ascent of water is mainly through the xylem vessels. In small herbs the height to which water is to ascend is small. In tall trees the height to which water is to ascend is very great. The question therefore is whether the water rises through dead xylem vessels or through the young living cells. In the former static forces such as capillary and mechanical and electric forces that move water under pressure or tension are operative. In living tissues movement of water is slow under pressure.

The ascent of water may be due to the following forces.

The forces operative in dead tissues are (1) **capillarity** (ii) **imbibition**, (iii) **electro-endosmosis** and (iv) **transpiration stream.**

The forces operative in living tissues and causing slow movement of water are (v) **sap pressure** due to osmotic gradients and (vi) **root pressure.**

(i) **Capillarity.**—Average xylem vessels measure 50m (0.05 mm.) in diameter. The height to which water can rise by capillarity in such tubes is very small compared to the height of tall trees. Capillary forces are operative in tubes open at both ends and which are dry. Xylem vessels are open at both ends and are already wet. It is possible that the imbibed water in the cellulose walls of xylem rises by capillarity.

(ii) **Imbibition.**—Wood absorbs water in large quantities and in the case of capillarity the rate of movement of water is too slow and the rapid movement of water witnessed in plants cannot be all due to this static force only.

(iii) **Electro-endosmosis.**—Differences in electric potentials bring about movement of water through capillaries. The electromotive forces may be within the plants or the electric charge of air in relation to earth may also cause movement of water.

(iv) **Evaporation** of water from leaves, or **transpiration** as it is called, induces a suction undoubtedly. Rise of water in plants by such a force is termed **transpiration stream.** The atmospheric air surrounding the leaves of plants is generally not

completely saturated. Therefore water must escape from the leaves into the atmosphere as vapour. That leaves lose water is obvious when they wilt. But they do not generally wilt while intact on the plant, because water is absorbed from below, almost equal in amount to the water transpiring from above. The cells in the leaves that lie in contact with the atmospheric air give up some water and this results in the concentration of the cell sap, which means more osmotic pressure. Since these cells are connected internally with the mesophyll cells water will be sucked, as it were from the cells by the former. This suction will be continued from cell to cell through the parenchyma and finally it reaches xylem vessels. This is the basis of **cohesion theory.** Evaporation of water from leaves, exert a pull on the water in lower surfaces which in turn draw water from xylem. For such a force to be effective, the water column from the leaf surface to the root hair must be continuous and this is assumed to be so. A cut branch placed in water is able to raise the water to its uppermost twigs. It is easy to prove that suction actually occurs in plants. Cut a vigorously transpiring branch and keep the cut end in water for some hours and then fit it to a long vertical glass tube filled with water by means of a rubber cork or tube. Close the other end with a finger and dip it in mercury contained in a vessel and withdraw the finger. Evaporation of water will go on from the leaves and the water within the tube will be absorbed. (Fig. 218). After sometime the mercury will rise within the tube to a considerable height.

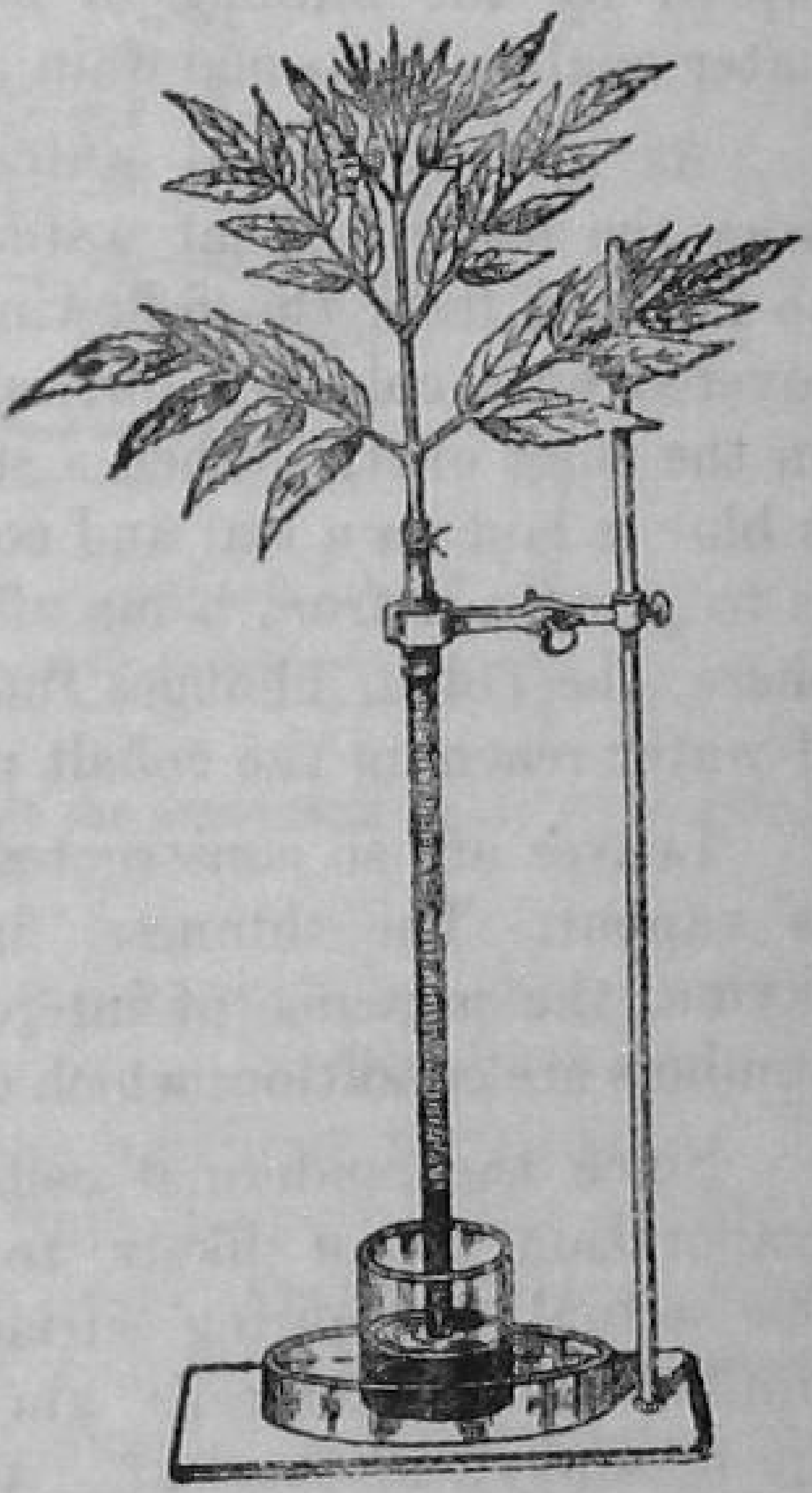


Fig. 218. Apparatus to show the suction power to transpiration.

This suction which is caused by transpiration from leaves is transmitted to the cavities of vessels and tracheids in the xylem. All these vessels are full of water at any rate, when they are young. At first in a young seedling there would be continous columns of water in each of the series of vessels, extending from the veins of the leaves, through the stem, to the root. As the seedling grows into a plant, new vessels filled with water are added in the root and

the stem, by the development of rows of cells some distance behind the growing points. So this continuous column of water is subjected to a pull from above on account of the transpiration taking place from the leaves. Even when the pull is considerable the column of water does not break. The suction from above instead of breaking up the column hauls it up bodily. It is a well-known fact that a continuous column of water in a closed tube with its walls wetted by it behaves like a rigid solid in the matter of transmitting tension. Even when the column of water is interrupted by the bubbles of air the cohesive power possessed by water enables it to maintain a continuous column.

As already stated water escapes in fairly large quantities from the leaves. That water actually escapes as vapour has to be inferred from the following observations. If a leafy twig is covered by a cold bell jar, after sometime drops of water collect on the sides of it. When a small piece of dry cobalt paper which is blue is laid on a leaf and covered by a piece of glass or mica, so as to protect it from being affected by the moisture in the atmosphere, the colour changes into red soon. This is due to vapour of water reaching the cobalt paper.

Leaves are so constructed as to facilitate the escape of water as vapour. The thinness, flatness, the arrangements of parenchyma, the presence of intercellular spaces and stomata in large numbers are conditions which are very favourable for transpirations.

Since the epidermal cells are cutinised on the free surface evaporation is not likely to take place through the surface. The actual transpiring surface is the surface of the enormous number of internal cells, abutting on the intercellular spaces in the mesophyll of the leaf. As the air in contact with these cells is not saturated, imbibition water of the cell walls will escape into the spaces as vapour. This loss is immediately made good by withdrawal of water from the protoplasm, lying in contact with the cell wall on the inside. The protoplasm in its turn draws water from the vacuole. This movement of water from the interior of the cell to the intercellular space affects the cell by causing concentration in the cell sap. In consequence of this concentration of the cell sap, water will be drawn in by this cell from the adjoining cells which are not themselves transpiring. As this process passes from cell to cell, the loss of water extends from the superficial cells where evaporation is taking place to the depths of the tissue.

The amount of water transpired by the leaf surface of a plant during the day time is very considerable. A tall well grown

sunflower plant is said to lose by transpiration about a litre of water in a day, and a large tree about five hundred litres of water.

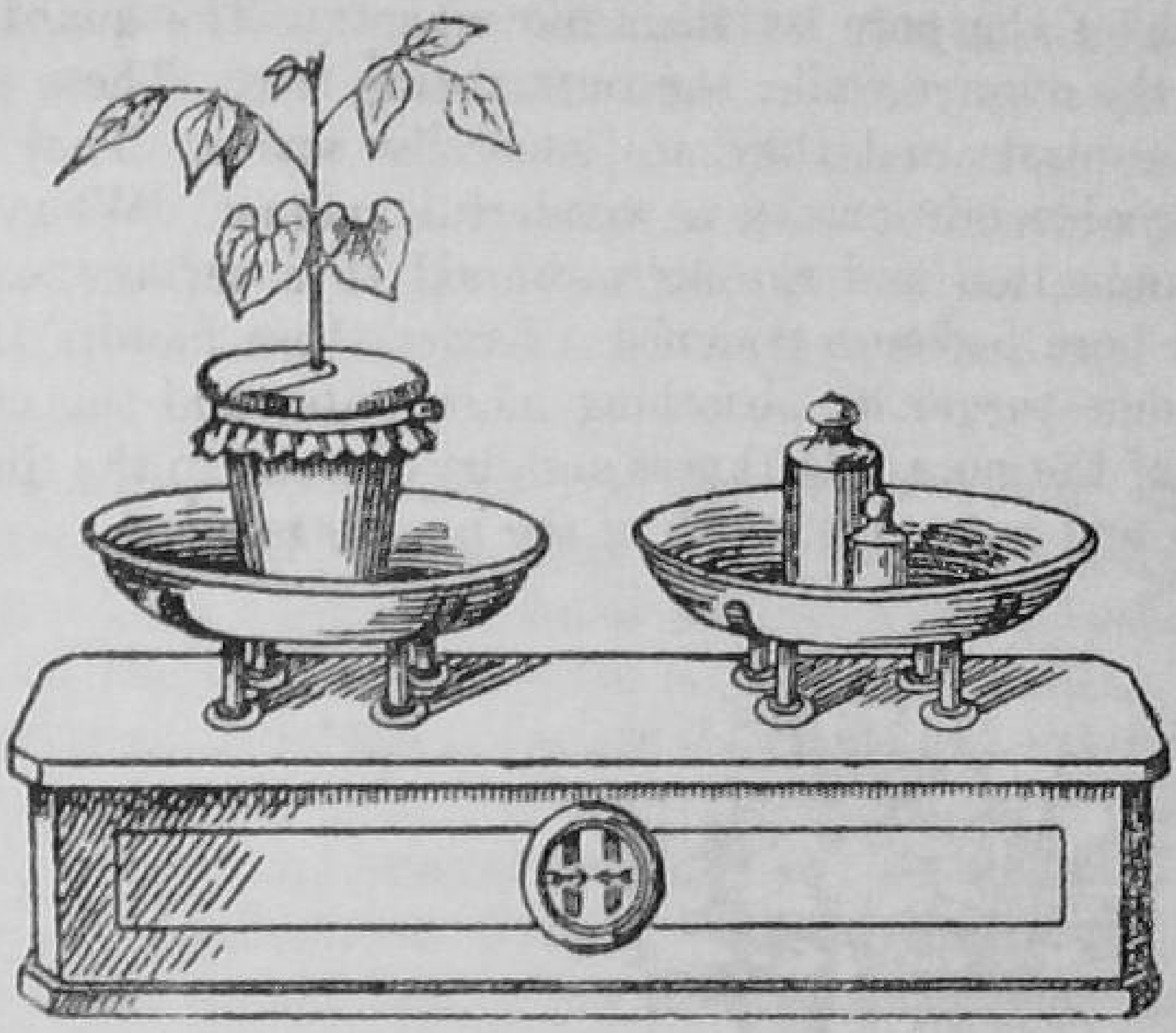


Fig. 219. Apparatus to determine the amount of water transpired by a plant by weight.

The amount of water escaping as vapour by transpiration from a plant can be determined easily by weighing the plants growing in pots. (Fig. 219). Before weighing they should be covered so as to prevent evaporation from the pots. The quantity of water transpired, however, depends upon various factors, such as the structure of the leaf, temperature and humidity or dryness of the air. Leaves possessing a large number of air spaces in the mesophyll are likely to lose large quantities of water. Dry air will increase the amount of water transpired, whilst moisture in air retards the process considerably. High temperature and well diffused light are favourable to transpiration but low temperature and darkness minimise the loss. Leaves lose more water on a windy day than on a quiet calm day.

In a typical land plant stomata play a great part in transpiration and, as a matter of fact, **stomatal transpiration** only is of importance in this connection. It is only in plants inhabiting moist situations the **cuticular transpiration** becomes considerable. Though the openings of the stomata are extremely small, their distribution and presence in enormous numbers compensate for their minuteness. A sunflower leaf is said to have about thirteen million stomata.

The stomata play a very important part in the regulation of transpiration. They not only facilitate transpiration, but also can stop it. The guard cells of the stomata are capable of altering the width of the pore by their movements. The guard cells are fixed at their inner walls, the outer being free. These cells contain chloroplasts and they are generally active. They react to the external conditions in a wonderful manner. When there is good illumination and the air is humid to a certain extent, the stomatal pore becomes widened. Under these factors the guard cells become turgid by absorbing more water and this causes the opening of the pore. Darkness and dry air lead to the diminution of turgor and hence the width of the pore is reduced.

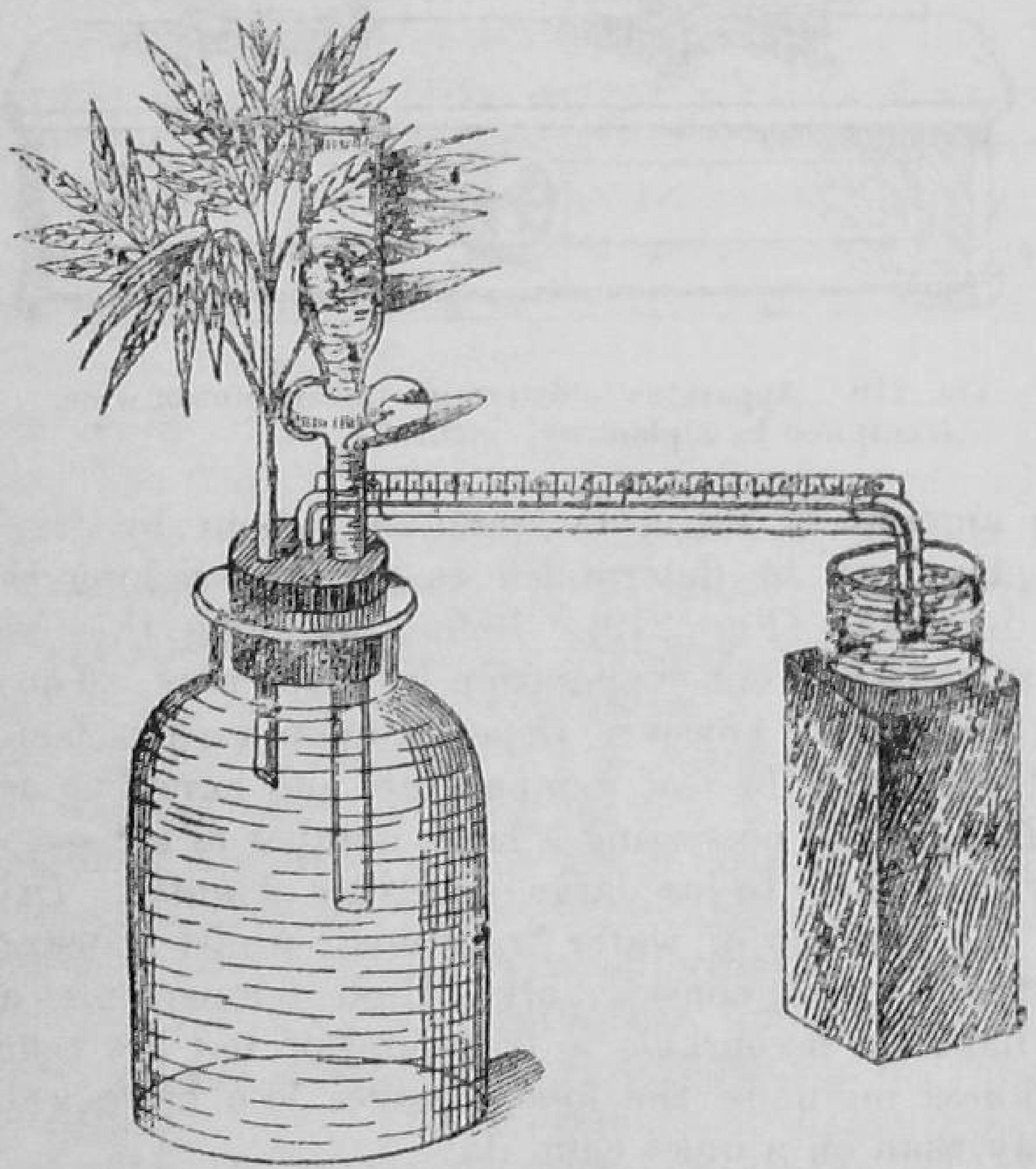


Fig. 220. Farmer's Potometer.

Transpiration from the leaves of branches cut off from the plant is usually determined indirectly by the use of a set of apparatus called **potometer.** (Fig. 220). The rate of transpiration from the leaves of a cut branch is more or less equal to the rate of absorption and, therefore, the amount of water absorbed may be taken as a measure of the loss of water by transpiration. There are several types of potometer but the one devised by Farmer

is convenient to use. This consists of a wide mouthed bottle fitted with a cork in which are bored three holes, the one intended for the cut branch being a little larger than the other two. The smaller holes are intended for the insertion of a thistle funnel tube with a stop-cock or a glass rod and a capillary tube bent at the two ends and provided with a scale. The branch intended for the potometer must be cut under water and left in it overnight. The fixing of the cut end of the branch to the rubber cork, and the insertion of the funnel tube and the bent tube should be done under water.

The general arrangement may be inferred from the figure. All connections ought to be made water tight by using wax or plasticine. After allowing a small bubble of air to get into the free end of the capillary tube, it is dipped in water. This air bubble serves as an index to measure the amount of water absorbed. By manipulating the funnel tube or the glass rod, the air bubble may be sent back and several readings may be taken. The potometer devised by Professor Ganong is also a very useful one, and it is easy to set up and can be got ready within a very short time.

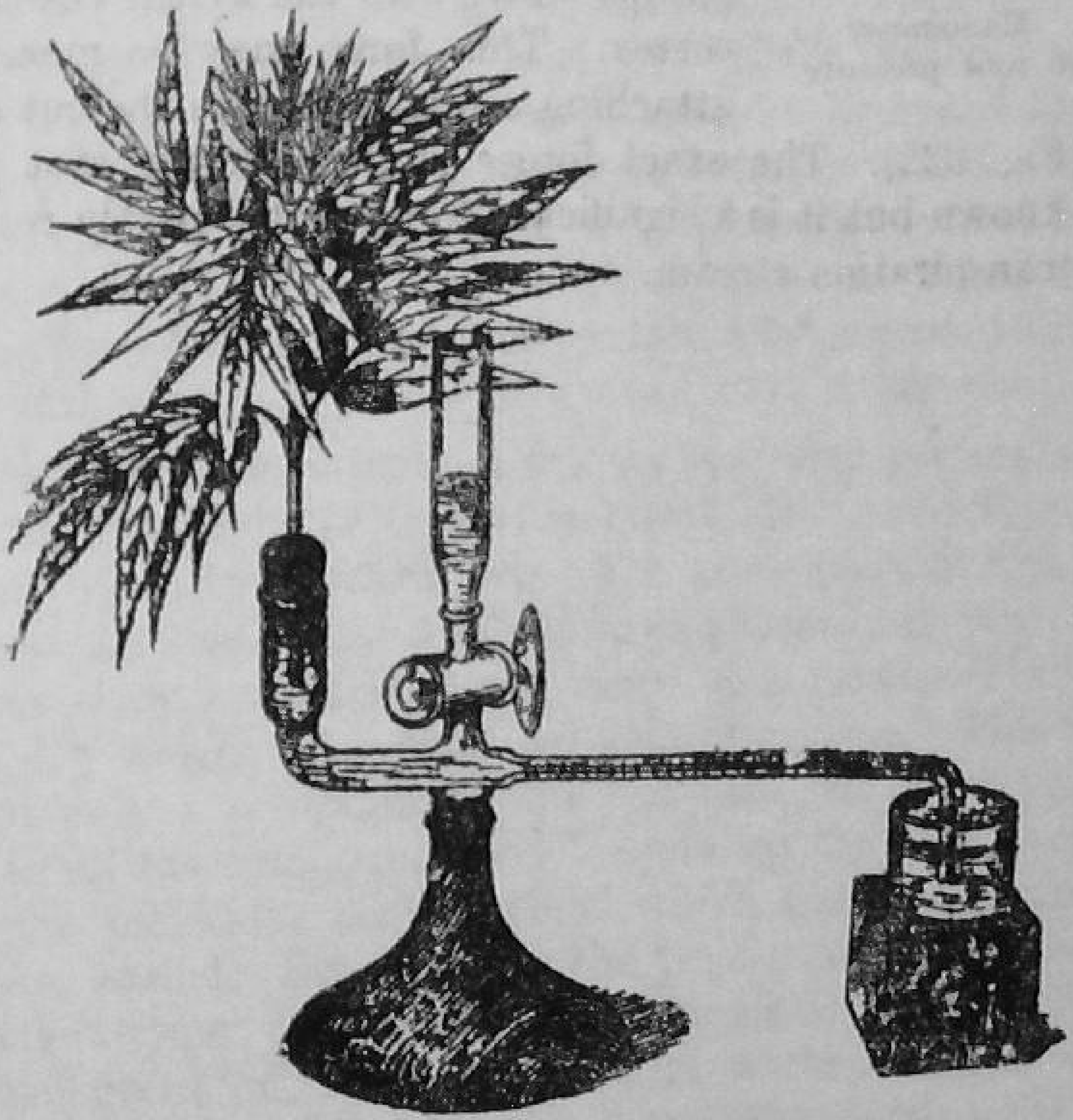


Fig. 221. Ganong's Potometer.

The method of setting up and using this set of apparatus may be learnt from the illustration in Fig. 221.

(v) **Osmotic gradient.**—If water is to rise by osmotic gradient then the concentration of salts at the root end must be least and it must slowly increase towards the leaves. In plants there is salt concentration gradient from root to leaves and on account of this salts rise from root to leaves. This results in osmotic gradient causing rise of water.

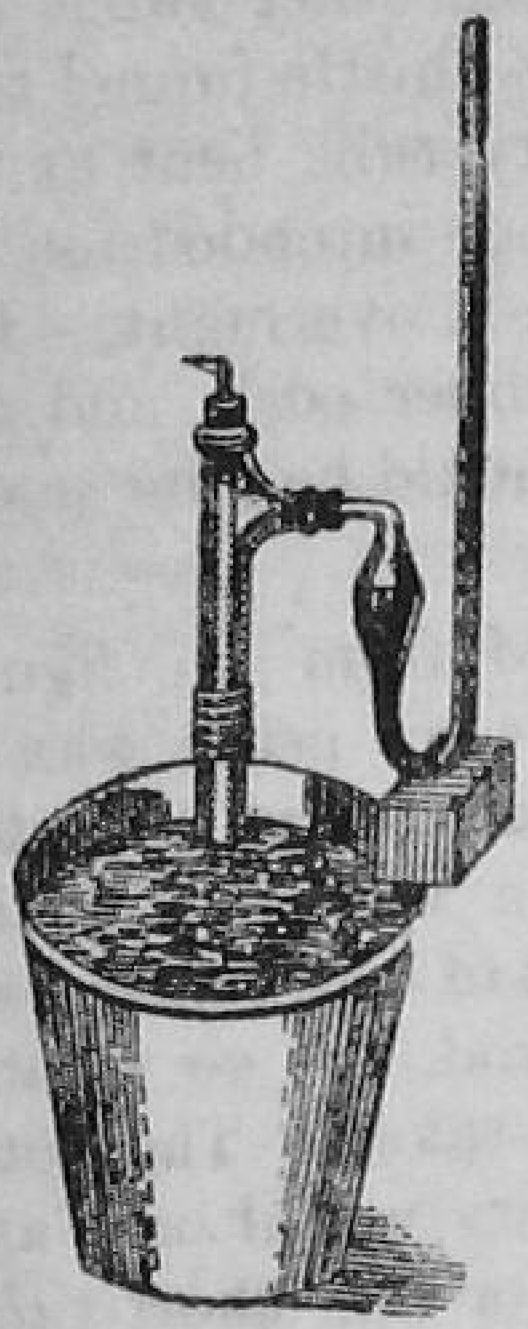


Fig. 222. Manometer to measure root pressure.

(vi) **Root pressure.**—When a stem is cut it bleeds. Bleeding is of economic importance in that tapping of toddy, exudation of turpentine and other plant juices are dependent on this phenomenon. Bleeding in many cases is continuous and is ascribed to root pressure or exudation pressure. When the evaporation from leaves is very great, root pressure is low and it is high only when evaporotion is lessened. Root pressure is a force that pumps water into the xylem vessels from cortex. This force may be measured by attaching a manometer to the cut end of a plant. (Fig. 222). The exact forces responsible for root pressure are not known but it is a significant force that is partly responsible for the transpiration stream.

CHAPTER XIX

NUTRIENT SALTS, WATER-CULTURE AND SAND-CULTURE

The water in the soil contains a number of mineral salts of which many are useful for plants, and the salts at the disposal of plants on the surface of the earth are really unlimited. Water is generally available over a large part of the surface of the earth. This accounts for the existence of green vegetation everywhere in the world.

Under natural conditions, higher plants, as a rule, absorb the nutrient salts along with the water that is taken in by the root hairs. Although many soluble salts are present in the soil, all of them do not enter the cells. We know that the protoplasm acts as a semi-permeable membrane and, therefore, we cannot expect all the salts to pass through it. It must be borne in mind that the permeability of the protoplasm is not the same always and that its impermeability is not absolute for any salt. The absorption of a substance seems to be dependent upon the external limiting layer of protoplasm. The wall of the vacuole also possesses this power of regulating what shall be absorbed and what not. In consequence of this power, substances which are found in very minute quantities in water may be taken in and accumulated, and substances found in abundance in water may be rejected. For example, sea-weeds contain a large amount of iodine in them although only traces of it are found in sea-water.

When plants are burnt in a fire, at first they get charred and, in the end, the whole of the lot is burnt away, and there is left only some quantity of white ash. The conversion of the part of plants into charcoal, while combustion is proceeding, is a sufficient proof that there is carbon in the body of a plant. Very nearly half the dry weight of a plant consists of carbon. This element forms not only a predominant one but also the most important element in all the compounds which build up the living organism, because the molecular combinations which carbon is capable of forming are varied. Since during the process of combustion of a plant, water vapour, carbon dioxide, ammonia and a gas containing sulphur are given off, it is evident that water, carbon, nitrogen and sulphur besides the ash must form the constituents of the plant body.

The ash constituents contain mineral salts and the mineral salts present in plants are essential for the growth of the plant.

From ash analysis we learn that the elements—potassium, magnesium, phosphorous, sulphur, iron, silicon, chlorine and sodium—are universally present in plants, and therefore, they are of general occurrence. At the same time, we must bear in mind that because a substance is invariably present in a plant, it does not necessarily follow that it is essential. What elements are essential and what are not can be determined only by experiment. Taking advantage of the fact that plants take in everything they need through the medium of water, we can grow plants in glass jars containing distilled water to which certain known salts are added, in some definite proportions. This method of rearing plant is called **water culture.** Plants may also be grown in pure sand by watering them with the prepared solution. This is **sand-culture.**

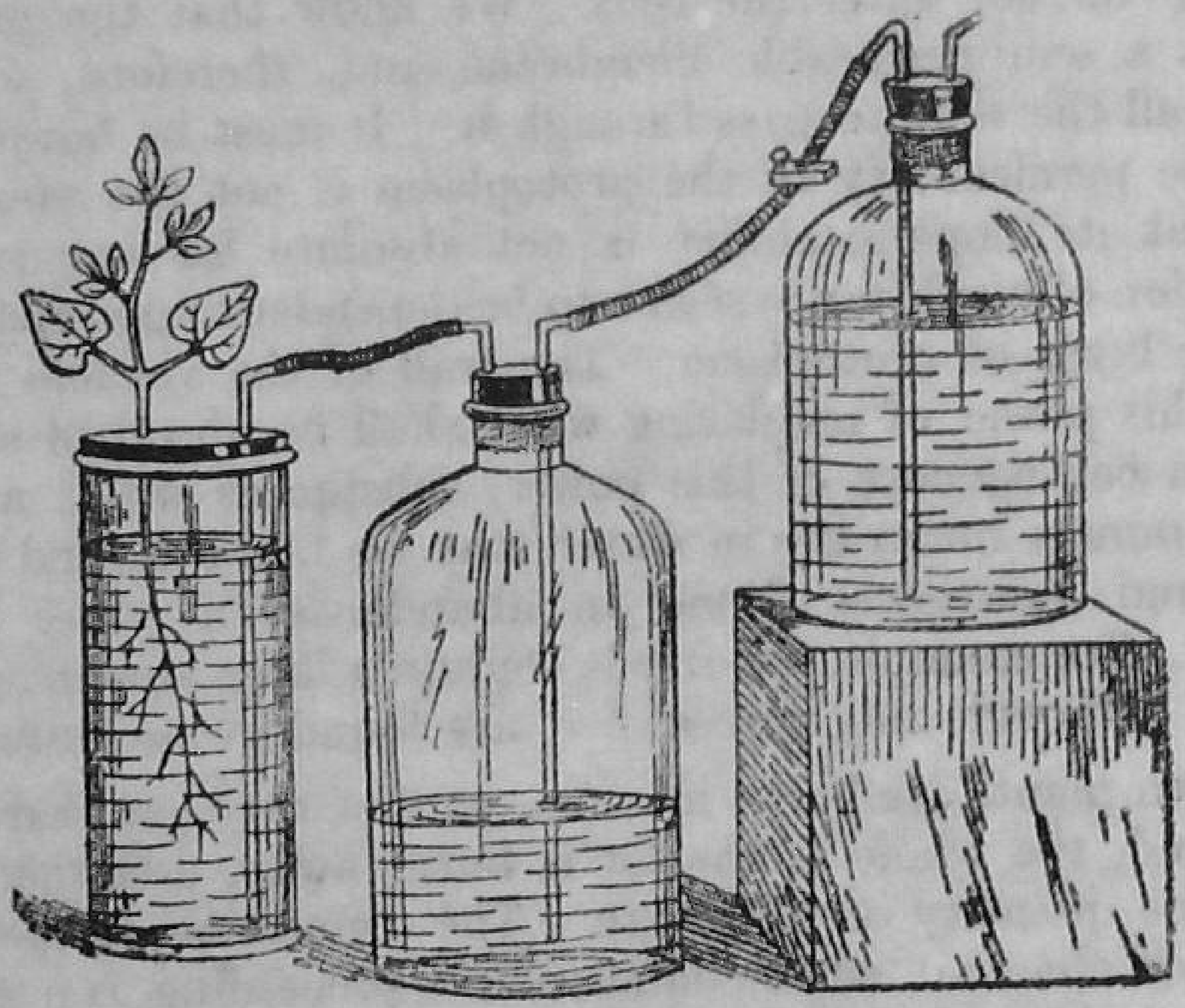


Fig. 223. Apparatus for aerating water-culture jars.

Water-culture

For water-culture experiments, seeds whose seedlings are capable of rapid growth, such as those of beans and maize, are germinated in sterilised moist sawdust or sand. When the radicle is well developed, the seedling is fixed in the lid of the glass jar as shown in fig. 223. For success in water culture experiments the jars must be thoroughly rinsed with dilute nitric acid first, and then with an aqueous solution of corrosive sublimate. By repeated washing with boiled distilled water all traces of corrosive sublimate should be removed, as this substance is a deadly poison.

WATER-CULTURE EXPERIMENTS IN DIFFERENT SOLUTIONS

To face page 245

There are many kinds of solutions used for water culture, but the simplest and the one giving good results is that known as Von Crone's solution. This consists of 1 or 2 litres of water, potassium nitrate 1 gramme, calcium sulphate 0.25 gramme, magnesium sulphate 0.25 gramme and ferrous phosphate 0.5 gramme.

For fixing the seedling in the lid of the jar it is best to use asbestos wool sterilised by burning it in the flame of a spirit lamp or gas burner. As the culture solution can keep in solution only a small amount of oxygen, it is necessary to force air into the culture solution in the jar, at least once a day for fifteen minutes in the form of small bubbles so as not to cause any damage to the roots. A very simple and convenient method of forcing air into the culture solution is shown in Fig. 223.

Essential Elements

The salts used in culture solution consist of the elements **nitrogen, sulphur, phosphorus, potassium, magnesium, calcium** and **iron.** All these seven elements and the three elements **hydrogen, oxygen** and **carbon** are absolutely necessary for the growth of plants. Hence these ten elements must be considered as the **essential elements** for the growth of plants. Plants grow to maturity, flower and set good seed only if they are supplied with salts composed of the seven essential elements mentioned above. Recent investigation has shown that exceedingly minute amounts of others, namely **boron, manganese** and **zinc** are also necessary. Actual bulk of these various mineral nutrients taken up by the plant is very small in proportion to the size of the plant body, but in the activities of protoplasm each plays a necessary part and a soil which is deficient in any one of them will be unable to support vegetation successfully. Hence the necessity for a chemical analysis of the soil in scientific agriculture in general and in particular where there is a doubt regarding soil fertility. If the culture solution is defective in any one of these elements, plants do not grow well. For instance, if in the culture solution ferrous phosphate is omitted and calcium or potassium phosphate is added instead, the element iron will not be available. A plant grown in a solution wanting in iron would have pale yellow leaves instead of green leaves. The results of the growth of plants in defective solution may be inferred from Fig. 223-A.

The amount of salts needed is indeed very small. Further, the essential elements must always be presented in the form of appropriate chemical combinations, because the nutritive value

depends upon this. For example, all substances containing nitrogen are not suitable. Most plants obtain these elements from nitrates and some from compounds of ammonia.

All plants need a supply of Nitrogen and it cannot be absorbed directly from the atmospheric air, though it is present in the atmosphere in large quantities. The supply to the plant is from the nitrates found in the soil and this salt is soluble in ordinary water. Being soluble in water, the water that flows about contains this salt and so it is liable to be carried by river water to the sea. In consequence of this flow, plants are in danger of losing nitrogen. Plants, we know, need nitrogen for their growth. Fortunately for plants, the bacteria (already referred to under soils) are known to take in the atmospheric nitrogen gas and fix it in the soil. These bacteria live in the root nodules of Leguminous plants and hand over the nitrogen compounds to these plants. These plants in their turn give them to the soil by decomposition in the form of ammonium salts and nitrates.

In the case of some plants, the presence of a non-essential element may be a distinct advantage to the plants. For example, the presence of silicon in the epidermal cells of certain plants may protect them from the depredations of insects, and thus save them from extinction.

Those elements which we consider essential enter into the composition of the protoplast. We know that the elements found in the protoplasm are carbon, hydrogen, oxygen, nitrogen and sulphur.

The Role of the Elements

The mere presence of an element in ash is no indication of its importance to the plant. The essential elements noted above may prove to be **nutritive** or **regulatory.** Carbon, hydrogen, oxygen and nitrogen are nutritive. Potassium and calcium are **regulatory.** Sulphur and phosphorus are both **nutritive and regulatory.**

(i) **Carbon, Hydrogen** and **Oxygen** are the most important constituents of protoplasm. They are also important constituents of food, cellulose, and other accessory products.

(ii) **Magnesium** is mainly found in seeds and young tissues. It is a constituent of chlorophyll and as such is most important in green plants. It is regulatory in function in non-green plants.

(iii) **Potassium**—Most of it is found in meristems. It is necessary for the vital activity of protoplasm but it is not a constituent of it. It is purely regulatory or catalytic in function.

Its presence is necessary for the formation of starch and it augments the synthesis of proteins and fats.

(iv) **Sulphur**—It is a nutritive element and is an important constituent of amino-acids. It is regulatory in the formation of chlorophyll.

(v) **Phospherus**—It is an important constituent in many proteins and particularly nucleo-proteins. It is present in all living cells.

(vi) **Iron**—This is important as oxygen carrier. It acts as a catalyst in the synthesis of chlorophyll. In its absence the plants turn **chlorotic.** (*Vide* colour plate)

(vii) **Calcium**—It plays a role similar to that of potassium but it also enters into the building up of frame work. It is utilised in the formation of cellulose walls. It renders poisonous oxalic acid to harmless calcium oxalate. It is important in legumes.

The following are some of the trace elements :—

(i) **Manganese**—Its importance is established beyond doubt. It is necessary for normal metabolic processes, protein synthesis and production of chlorophyll.

(ii) **Boron**—This is assuming importance more than as a trace element. It occurs widely in plants but only in minute quantities. Its exact function is not known but it is an activator of physiological processes and is essential for normal growth.

(iii) **Zinc** is important in certain cases. In citrus trees, its deficiency causes mottling of leaf.

(iv) **Silicon** adds stiffness. It is especially deposited in the margins of leaves of grasses; it is also suggested as increasing resistance of plants to diseases.

CHAPTER XX

PHOTOSYNTHESIS AND FOOD OF PLANTS

Photosynthesis

From water culture experiments we have learnt that certain mineral substances are essential to plants, and also, that plants obtain all the elements required for their nutrition excepting carbon, from the soil in the form of water and mineral salts. Although a small portion of the water containing mineral salts absorbed by the roots passes by osmosis from cell to cell, to meet the local needs, the bulk of it passes as transpiration stream to the leaves. From the leaves this water escapes as vapour leaving behind the mineral substances. The mesophyll cells of leaves thus receive constant supplies of mineral substances, and yet we do not find any accumulation of these substances in the leaves. So it is obvious that these mineral substances undergo chemical changes and become constituents of complex organic substances found in plants.

The absorption of water and transpiration from the leaves are only means to an end, namely the manufacture of carbohydrates. The primary function of the leaf is undoubtedly the manufacture of carbohydrate. This process is termed **photosynthesis** or **carbon assimilation.**

The various factors that influence the rate of photosynthesis are :—

External factors :

(a) Light.
(b) Carbon dioxide.
(c) Temperature.
(d) Water supply.

Internal factors :

(a) Chloroplast.
(b) Accumulation of photosynthetic product.
(c) Protoplasmic.

Too much reliance should not be placed on the effect of one factor alone without considering the simultaneous influence of others. According to **Blackman's theory of limiting factors,** " when a process is conditioned as to its rapidity by a number of

separate factors, the rate of the process is limited by the pace of the slowest factor." For example, if light intensity is sufficient to decompose 10 c.c. of carbon dioxide and if the medium contains only 5 c.c, then the light intensity on the leaf is more than required. If the medium contains 10 c.c. of carbon dioxide, then the light intensity on the leaf is just sufficient. If the medium contains 15 c.c. of carbon dioxide, then the rate of photosynthesis cannot be increased without further increasing the energy supply by means of increased light intensity. Thus, if one of the factors is below the minimum level, an increase in that factor alone will increase the rate of photosynthesis.

Light.—For the production of sugar the element carbon has to be dissociated from the element oxygen, and the energy required for this work is very great. It is about what is expressed by the temperature 1300 degrees centigrade. We know that neither sugar nor starch can be manufactured by the chloroplasts if sunlight is not available. So it is evident that the **source of energy is sunlight.** However, it should be borne in mind that ordinary sunlight is unable to decompose carbon dioxide or water, and were it possible we should not expect to find carbon dioxide or water vapour in the atmospheric air. Light is absorbed and it is converted probably into electric energy which is made use of for photosynthetic work.

When an alcoholic extract of chlorophyll is interposed between the light and the spectroscope, the spectrum shows very dark bands in red and orange and hazy weaker bands in the blue. From this it has to be inferred that the chloroplasts make use of the radiant energy represented by the rays absorbed. That these rays are actually made use of by chloroplasts in photosynthesis can be easily demonstrated. When a plant from whose leaves starch has been depleted, by keeping it in the dark for sometime, is exposed to red or white light, plenty of starch is formed in the leaves, while under green light no starch is formed. A certain amount of starch occurs under blue light. A very ingenious method of proving that photosynthesis takes place very rapidly when plants are exposed to red light, and that the process is slow under other colours of the spectrum has been introduced by Englemann. Taking advantage of the fact that evolution of oxygen is an accompaniment of photosynthesis, he mounted a thread of an alga in water and exposed it to the solar spectrum, so that different parts of the green algal thread are illuminated by different coloured rays. A culture of the bacterium, *Bacterium thermo* which is very sensitive to oxygen was introduced very close to the thread of the alga. Largest number of the

bacteria were seen crowded close to the part of the thread which was illuminated by the red rays of the spectrum. This means oxygen appeared more in this part than in any other part. That is to say, photosynthesis is most active in the part receiving red rays.

Carbon dioxide.—Plants reared by the method of water or sand culture grow well, getting the required carbon all right although the culture solution contains no substance, containing the element carbon. While water and salts come from the soil, the gaseous substances, namely, oxygen and carbon dioxide are obtained by the plant from the atmosphere. We have sufficient reasons to infer that the manufacture of carbon containing substances takes place mostly in the leaves of plants.

The only gases that are necessary to the plant are oxygen and carbon dioxide. That oxygen is essential for all vital functions is easily understood, but not so the necessity for carbon dioxide. Since carbon forms about half of the solid constituents of plants, and since the synthesis of other organic substances also is dependent upon it, this gas is indispensable to the plant. We know that carbon dioxide is present in the air in small quantities in the proportion of 3 parts in 10,000 parts. When air containing carbon dioxide is supplied to a green plant exposed to good light under a glass case, the amount of carbon dioxide in the air diminishes or the whole of it disappears. A plant having a supply of air freed from carbon dioxide does not grow. So we have to conclude that the only source from which land plants obtain the carbon they need is the carbon dioxide of the air. The proportion of this gas in the atmospheric air being so small, it may be thought that the supply is inadequate. But, when we consider the actual quantity available in the vast space of air, it is really enormous. Further, every plant that burns, every bit of fuel that is burnt, every organic substance that is undergoing decay and every organism that breathes, produces carbon dioxide and thus augments the amount of this gas in the atmosphere. In other words carbon dioxide is constantly being returned to the atmosphere from which plants are taking them off.

Diffusion of oxygen and carbon dioxide. Both oxygen and carbon dioxide may enter the plant by the epidermis or stomata. These gases can pass into the epidermal cells only if their walls are moist with water, but not when dry. Since the epidermis of most plants becomes cutinised, the only way by which these gases can reach the interior of the mesophyll is through the stomata. To ensure a constant and steady supply of oxygen and carbon

dioxide plants develop in their bodies a regular aerating system. The stomata in the epidermis, the lenticels occurring in the older parts of stems and roots, and the most extensive intercellular spaces found in the parenchyma of plants constitute the aerating system. The supply of oxygen to all the meristematic cells being very essential intercellular spaces develop even amidst the cells in the growing point. These spaces are indispensable, because by mere diffusion from cell to cell oxygen cannot be expected to reach the places quickly where it is needed. Intercellular spaces being in communication with the exterior, air will get in quickly and occupy these spaces, and from here cells get the oxygen easily, as it is near at hand.

The carbon dioxide in the air enters the stomata and gets into the respiratory cavities adjoining them. These air cavities communicate with the air spaces in the spongy parenchyma. Even in the palisade parenchyma there are numerous small intercellular spaces. In fact, intercellular spaces are abundant in parenchyma wherever it may be found and more so in the mesophyll tissue. So the intercellular spaces in the leaves become continuous with those in the stem.

The stomata are very minute pores and therefore, it may be puzzling to think how these minute pores afford passage for a sufficient quantity of oxygen and carbon dioxide. But it is a demonstrated fact that air diffuses very easily and quickly through a membrane drilled with minute holes, especially when these holes are elongated slits. Further, the stomatal pores are not really small relatively to the molecules of oxygen or carbon dioxide. Professor Ganong has pointed out that the capacity of the stomatal opening for the passage of gas is far in excess of that implied by their areas, and that an ordinary stoma when open presents to a molecule of carobn dioxide or water an entrance or exit as great, as a passage seven miles wide appears to a man. Besides this the number of stomata present in the epidermis of a leaf is enormous. For example, in the leaf of the sunflower plant there are on the average, about 325 in the lower and 175 in the upper epidermis in one square millimetre of surface.

Other factors which influence the inflow or outflow of the gases are diffusibility and solubility of gases in water and their utilisation within the plant. The intercellular passages in the mesophyll of the leaves are in communication with the atmospheric air outside through the stomata, and therefore, all the intercellular spaces in the mesophyll of the leaves will be filled with the atmospheric air. But the composition of the air in the intercellular

passages is bound to be modified constantly, because there will be an interchange of gases between the cells and the air in the intercellular spaces. Carbon dioxide in this air will get into the mesophyll cells and this must cause a lowering of the pressure in the intercellular spaces of this gas. Consequently carbon dioxide will rush into the intercellular spaces from the air outside. Oxygen, on the other hand, will pass from the cell into the intercellular spaces thereby increasing the pressure of this gas in these spaces. So oxygen will move from the intercellular spaces to the air outside through the stomata. The air in the intercellular spaces being less saturated than the cells with water, water vapour diffuses into these spaces from the cells, and from thence it passes out into the atmospheric air, which is drier than the air inside the leaves. Thus we see that the direction of the passage of gases depends mainly on pressure and in plants there will always be difference between the air inside and outside the leaves, inasmuch as the gas carbon dioxide is used up and oxygen is liberated, and further their solubility and powers of diffusion are also different. Carbon dioxide is far more soluble in water than oxygen.

Temperature

The range of temperature in which photosynthesis can take place varies widely with different plants. When light intensity is weak, temperature has no influence and this is characteristic of photochemical reactions. When light intensity and concentration of carbon dioxide are high, temperature increases the rate of photosynthesis and this is characteristic of chemical reactions (Van't Hoff's rule).

Water Supply

Turgidity of the leaf tissue is essential for photosynthesis to take place. The rate of photosynthetic activity in leaves is directly proportional to the water content of the leaves.

Chloroplast

The green colour in plants is due to the presence of pigments in chloroplast. The following four pigments are present in the chloroplast.

Chlorophyll (*a*)	..	$C_{55}H_{72}O_5N_4M_g$	green.
Chlorophyll (*b*)	..	$C_{55}H_{70}O_6N_4M_g$	green.
Carotin ..	..	$C_{40}H_{56}$	orange red.
Xanthophyll ..	..	$C_{40}H_{56}O_2$	yellow.

In most Angiosperms, chlorophylls *a* and *b* are present in the proportion 3 to 1. In shade plants chlorophyll *b* is predominant.

The green pigment chlorophyll is confined to the specialised protoplasmic matrix called chloroplasts. Their arrangement within the cell is variable from time to time. A very large number of them is packed in each cell of the leaf. In castor leaf it is computed that nearly 5 lakhs of chloroplasts are found per square mm. Nearly four-fifths of them is in the palisade and one-fifth in the spongy tissue.

The chloroplasts expose a large surface on which various steps of chemical reactions in photosynthesis take place. In the case of one tree it is approximately computed that there are about 1 million leaves, which expose nearly 314 acre surface; the surface of the exposed chloroplasts is 16 acres.

Chloroplasts really perform two distinct functions, namely, the manufacture of sugar when illuminated and changing the sugar into starch, for which process illumination is not necessary. When living leaves free from starch are floated on sugar solution and left in the dark, starch makes its appearance in the leaves; leucoplasts also change sugar into starch.

The amount of sugar formed by photosynthesis is dependent upon the supply of carbon dioxide and the intensity of light. Upto a certain limit the more the carbon dioxide the more is the sugar formed. The chloroplasts need only a light of certain intensity and there is a minimum and a maximum intensity. Too strong a light not only retards the formation of sugar, but may also injure the chloroplasts. Chloroplasts, however, avoid the injury by shifting their positions in the mesophyll cells. Out of the light falling on leaves, only about 40 to 70 per cent. is absorbed by the leaves, and only 10 to 20 per cent. actually enters the chloroplasts, and the amount actually utilised in photosynthesis is still less, being only 0·5 to 3 per cent. **To have a general idea of the amount of sugar formed, we may say that one gramme of sugar is made by one square metre of leaf space in one hour in diffuse light.**

Accumulation of Photosynthetic Product

The soluble sugars formed in photosynthesis are osmotic substances and hence their accumulation in the assimilating cells will bring photosynthesis to a stop. Therefore, these soluble sugars are converted into insoluble starch. Too much accumulation of starch also brings the process to a standstill. The rate of

photosynthesis will be maintained only if the initial concentration of reactants is maintained and the products of reaction are removed.

Protoplasmic.—Besides chlorophyll there is some other internal factor concerned in photosynthesis. This is termed protoplasmic factor.

Tests for photosynthesis.—**Starch test** : From the study of germination of seeds we know that the embryo gets its food from the cotyledons or the endosperm, until it develops into a seedling. As soon as green leaves are formed, the seedling needs no reserve food, as it is able to manufacture its food. This being so we should be able to detect the food substances within the plant. By the use of an aqueous solution of potassium iodide and iodine the presence of starch in leaves may be demonstrated easily. If the leaves of a plant growing in the open be detached towards the evening before sunset from the plant, placed in alcohol after killing them by immersion in boiling water and, then, immersed in an aqueous solution of iodine, they become blue black, showing the presence of large quantities of starch. In the leaves of plants kept in darkness for a day or two and treated as above, we do not find any starch. When a starch free leaf detached from a plant kept in the dark is placed in a vessel of water and exposed to sunlight, starch makes its appearance in the leaf. In the same plant, if a leaf is exposed to sunlight for a few hours, after covering it with a stencilled tin foil or stout black paper, and then, if the same leaf is tested for starch in the usual manner, the letter stencilled appears black and the parts covered by the tin foil or paper remains white. We have, therefore, to infer that leaves are able to manufacture starch only when they are exposed to light, and only in parts of leaves actually illuminated by the rays of light (Fig. 224).

Fig. 224. Leaflet of *Dolichos lablab.* The leaf was covered with stencilled plate exposed to light for a few hours and then treated with iodine solution.

Starch is an organic compound having as its constituent elements carbon, hydrogen, and oxygen. Leaves always contain plenty of water, and this consists of the elements hydrogen and oxygen. Carbon dioxide gets into leaves and reaches the interior

of the cells, as it is a very soluble gas. Thus the constituent elements of starch and sugar namely carbon, hydrogen and oxygen are found in these substances, namely water and carbon dioxide which are always present in the cells of the chlorenchyma. The chloroplasts in the mesophyll cells prepare the carbohydrate material by combining the constituent elements, after separating them from the compound substances. The process of synthetic work going on in the leaves is called **photosynthesis,** because it is one of combining simple elements into a compound, and this is possible only in the presence of sunlight. The first visible product of photosynthesis is starch, and small starch grains are formed within the chloroplasts. However, in green plants sugar seems to be formed at first in the chloroplasts and most of this sugar passes into the cell sap, although some of it may pass on to other parts of plants through the veins of the leaves. This passage of the sugar into the cell sap must necessarily lead to concentration of this within the cells. Transformation of sugar into starch is essential if this accumulation of sugar in the cell sap is to be prevented. Concentration beyond a certain point affects the activity of chloroplasts. Starch does not in any way interfere with the osmotic activity of the cells.

Evolution of Oxygen

That oxygen is given off when photosynthesis is going on, can be demonstrated very easily. Fill a narrow glass jar or a test tube with water and support it inverted over a large glass jar, also filled with water and previously charged with carbon dioxide. Place a few vigorous shoots of *Hydrilla* or *Vallisneria* in the larger jar and just thrust the cut ends of these into the narrow jar or test tube so that they may project a little into the jar or test tube and keep the apparatus in diffused sunlight for some hours. Note the evolution of bubbles and, when sufficient gas has been collected, invert the narrow jar by closing its mouth with a ground glass and introduce a red hot splinter into it. The flaming of the splinter shows that the gas evolved is oxygen (Fig. 225).

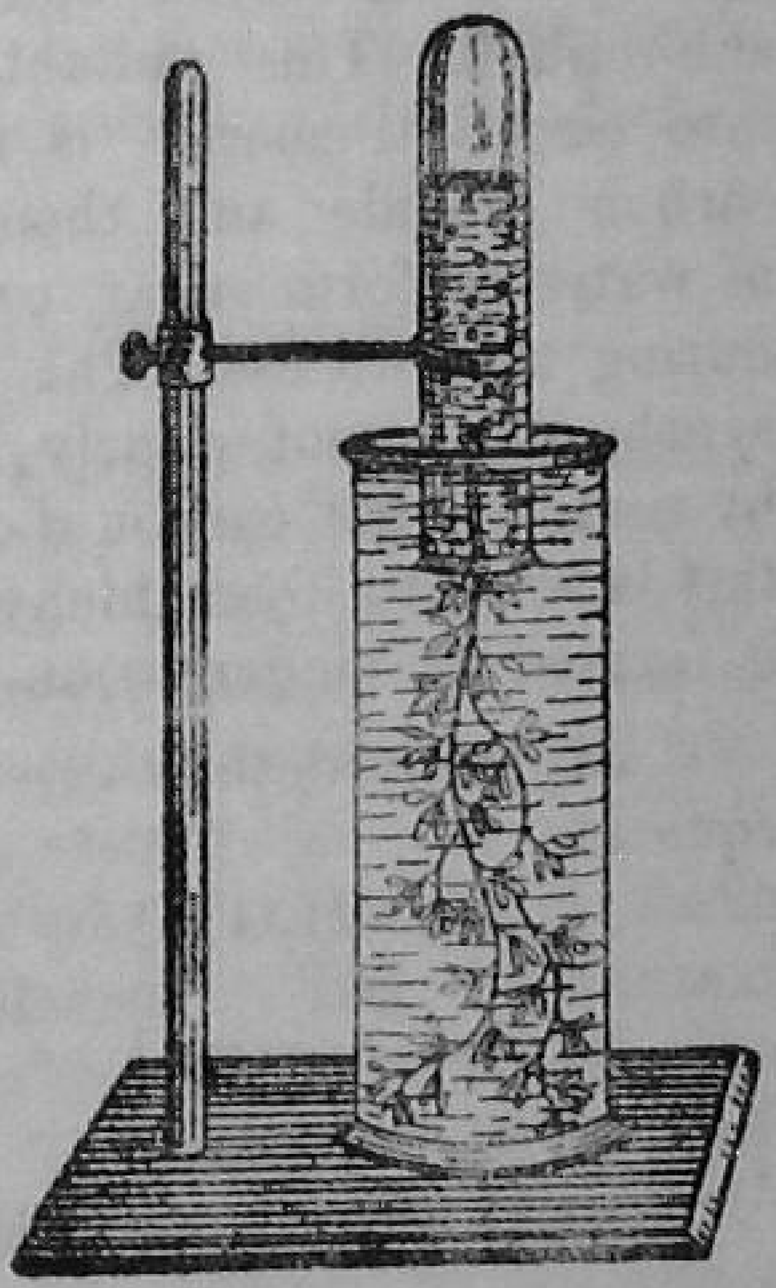


Fig. 225. Apparatus for showing the evolution of oxygen from plants during photosynthesis.

The evolution of bubbles varies with the intensity of light. When exposed to bright sunlight, the number of bubbles given off is much less than in diffused light. In shade and in dim light the number of bubbles is further reduced. In the dark there will be no bubbles.

Since the evolution of oxygen is an accompaniment of photosynthesis, it should also be affected by different colours of the solar spectrum. Take two large wide mouthed glass jars and partly fill one of them with a solution of potassium bichromate and the other with ammoniacal copper sulphate solution. Into each lower a narrow jar placing in the latter some weight so as to sink it in the solution. Introduce a healthy *Ottelia* or *Vallisneria* leaf into another small glass jar filled with water keeping the cut end of the petiole below water and place this jar within the second jar. Cover the mouth of the jars so as to exclude white light and leave the apparatus exposed to good diffused sunlight. Compare the rate of evolution of bubbles in the two different lights, namely, orange and blue. Under the orange colour the bubbles come out as under diffused white light, but under the blue colour they come out very slowly and at long intervals, or they do not at all come out.

Chemistry of Photosynthesis

When chloroplasts are illuminated they absorb the rays of the spectrum corresponding to the bands of absorption of chlorophyll. This radiant energy, after becoming transformed into electrical energy, is used in splitting up the molecules of carbon dioxide and then combining them with the elements of water to form sugar, oxygen being liberated at the same time during the process. The exact details of the process of photosynthesis are not clearly known. But the hypothesis advanced by some in that carbon dioxide is first reduced to formic acid and this later into formaldehyde. From formaldehyde glucose sugar is formed by condensation.

All these details are shown below by means of chemical equations :—

$$\left.\begin{array}{c} CO_2 + H_2O \\ \text{or} \\ OH.\,COOH \end{array}\right\} \rightarrow H.\,COOH + O$$

(Carbonic acid) (Formic acid).

$$H.\,COOH \rightarrow H.\,COH + O$$

(Formaldehyde).

$$6\,(H.\,COH) \rightarrow C_6\,H_{12}\,O_6$$

(Grape sugar).

In most green plants, if not in all, the excess of sugar, after a certain degree of concentration is reached, is converted into starch by condensation, and this forms small grains in the substance of the chloroplast. This may be represented by a chemical equation thus :—

$$n(C_6 H_{12} O_6) \rightarrow (C_6 H_{10} O_5) n + nH_2O.$$

The formaldehyde hypothesis was advanced by Baeyer. It has not yet been proved that formaldehyde is normally formed in the green leaves or that it plays any part in photosynthesis.

Warburg considers that photosynthesis takes place in two stages: (a) **photochemical reaction** forming a primary product which is proportional to light energy absorbed (b) **chemical reaction** between this primary product and an "**acceptor.**"

First Sugar of Photosynthesis

Starch is the first visible product of photosynthesis. It is a storage product. In a large number of plants, starch is not formed in the assimilating tissues. Starch is a complex molecule and hence it cannot be directly formed from water and carbon dioxide. It is later synthesised from the first formed simple sugars. The products of photosynthesis are glucose, fructose, sucrose and starch. Which of these is first formed is not yet definitely known. Till recently it was suggested that sucrose is the first product of photosynthesis. There are also evidences to show that hexoses are the first product of photosynthesis. Sucrose is the main form in which the carbohydrates are translocated in plants and it is the best starch former.

Structure of Leaf in Relation to Photosynthesis

Photosynthesis takes place in chloroplasts. These chloroplasts occur in the cortical cells of green stems and aerial roots and mainly in the inner tissues of leaves. Of all the other green parts of the plant, it is the leaves that are well adapted in structure for photosynthesis. In land plants chloroplasts are most abundant in palisade tissue. The epidermal cells, except the guard cells of stomata, do not generally bear chlorophyll. The chloroplasts generally line the thin cell wall of these tissues. The chloroplasts are distributed in the inner layers only and these layers are covered up by epidermis on both the upper and lower surfaces of the leaf. The carbon dioxide of the atmosphere has no direct contact with the chloroplasts. It slowly diffuses to the inner tissues from the outer atmosphere. The entrance of this gas into the leaves is chiefly through the stomatal openings. The epidermis

being usually dry and also cuticularised, it is impervious to this gas.

When the stomata are open to facilitate the passage of carbon dioxide into the mesophyll, there is nothing to prevent water from escaping as vapour through the same way. Transpiration is therefore an unavoidable accompaniment of photosynthesis, and this process of evaporation, though incidental instead of being primary, is useful, as it is an important factor in maintaining the transpiration stream which is necessary to supply water as well as salts to the chlorenchyma. Another advantage of transpiration is the prevention of injury from excessive heat to the plant by lowering the temperature.

The student may feel that this restriction to the free passage of carbon dioxide, *viz.*, the necessity to pass through minute stomata will decrease the efficiency of the gaseous exchange. The area of stomatal pore is several million times greater than the area of a single Co_2 molecule; figuratively, the stomatal opening is equal to a door way 7 miles broad for a single man to pass through. It has been computed that the diffusion of Co_2 through the stomata is 50 times more than what it will be through a single pore as wide as the total area of the stomata. Therefore, the stomatal apparatus is a contrivance to increase the rate of gaseous diffusion between the external atmosphere and the internal tissues of the leaf in a most efficient manner.

The carbon dioxide may also reach the inner layers by **cuticular diffusion**; which is possible only as a solution in the moisture of the cuticle. Such a diffusion is small in land plants but is common in aquatic plants in which stomata are generally absent.

The leaves are adapted for the quick transport of the products as well as the raw materials of photosynthesis. Moisture supply is steadily maintained by the xylem vessels of the veins that ramify the lamina. The finished products reach phloem through the passage cells. These are quickly transported down to the regions where they are needed. The various enzymes to deal with the conversion of insoluble to soluble products and *vice versa* are also present in the leaves.

Thus the leaves are well adapted to carry out photosynthesis very efficiently.

Functioning of stomata

Since the diffusion of carbon dioxide from the outside atmosphere to the chloroplasts inside the leaf is mainly through the stomata, the opening and closing of the stomatal pore is

important. Each stoma consists of bean shaped guard cells which enclose a pore between them. Beneath the stomatal pore lies the **respiratory cavity** which is an air space serving for interchange of gases and water vapour between the external atmosphere and the inter-cellular spaces of the leaf. In transverse section, the thickening of cell wall of guard cell is seen at the upper and lower edges of the pore. The convex wall next to the pore and away from it are thin. When the guard cells are turgid, the thin walls stretch and open the pore. With loss of turgidity in the guard cells, by the removal of water the cell walls sag and close the pore.

The stomatal movements are brought about by changes in osmotic pressure. These cells contain chloroplasts. When illuminated, sugars are formed and osmotic pressure also increases. Such an increase in osmotic pressure results in water getting into guard cells from the surrounding cells. This increases the turgidity of the guard and due to the special anatomy of the cells the stomata are widened.

When the sugars are reconverted into starch, the osmotic pressure of guard cells decreases. Water is drawn away from them resulting in the sagging of guard cells and the closing of the pore.

CHAPTER XXI

NITROGEN METABOLISM IN PLANTS

Proteins

The process of food making is not completed with the formation of sugar. As protoplasm consists mostly of proteins, besides sugar, nitrogenous organic substances also are needed in the nutrition of plants. Plants are synthesising-machines and as such the complex nitrogenous substances found in them are synthesised from simple compounds such as nitrates, ammonium salts, carbon-dioxide,water, sulphates and phosphates. Animals, on the other hand, cannot synthesise proteins from such elementary forms but requires nitrogen to be supplied in the form of proteins. The exact steps involved in the synthesis of proteins in plants are not yet completely understood.

Proteins are essential for all life processes. They are compounds of high molecular weight. For example, the formula for gliadin found in wheat kernal is $C_{685}\ H_{1068}\ O_{211}\ N_{196}\ S_5$.

On hydrolysis, the proteins split up into amino-acids, of the general formula R-CH (NH_2) COOH.

Nitrogen Supply

Green plants, normally absorb the inorganic salts of nitrogen through the roots. Nitrates and ammonium salts are the chief forms in which nitrogen is taken up by plants. But, in Leguminosae, bacteria in the roots fix up atmospheric nitrogen. While the bacteria convert the free nitrogen of atmosphere into organic compounds and supply the same to plants, the latter supply organic compounds to the bacteria. This phenomenon of mutual help is termed **symbiosis.**

The soils contain nitrifying bacteria which are capable of converting ammonium compound into nitrates. In which of these two forms, nitrogen is utilised by the plants depends upon factors affecting soil condition and plant growth.

Protein Synthesis

The process of protein synthesis is not restricted to any particular organ like photosynthesis. The presence of chloroplasts is not a necessary condition because plants without chloroplasts,

such as fungi are able to manufacture proteins. It can take place in light as well as in darkness and possibly in any living cell. In spite of the fact that in any living cell this process can go on, there is every reason to think that most of this work is carried on in the leaves. Large quantities of nitrogenous substances in the form of amides are found in mature leaves, especially when their activity is at its height, and this cannot be accounted for except by thinking that it is made in the leaves.

For the elaboration of proteins substances containing the element carbon, hydrogen, oxygen, nitrogen, sulphur and phosphorus are needed. Inasmuch as sugar contains carbon hydrogen and oxygen it is evident that this substance can be utilised as a foundation material in the process of protein synthesis. The water which is absorbed by the roots and which reaches the mesophyll of the leaves contain salts such as nitrates, sulphates and phosphates. Since amides make their appearance in leaves we have to suppose that carbohydrates are converted into amides. Later on amides become modified into several kinds of proteins by the incorporation of the elements sulphur and phosphorus contained in the sulphates and phosphates. The energy needed for the dissociation and combination of this protein synthesis comes from chemical actions connected with respiration.

In this world the only place where organic matter is formed from simple inorganic substances is the green leaf. All organic matter existing in this work, however different they may be and wherever they may be found, must have been derived or formed from substances manufactured by the leaf. **So nature's laboratory for the formation of organic matter is the chloroplast found in green plants.** The life of the whole of the organic world is dependent on the process of photosynthesis. If there is no photosynthesis no animal can live. All the stored up energy of this world is traceable directly or indirectly to this process.

Nitrogen assimilation of leguminous plants

Though the atmospheric air abounds in free nitrogen, it is not directly assimilable by all plants. The nitrogen requirements of all plants are met by the absorption of salts especially nitrates and ammonium salts through the roots in soil. The Leguminous plants, such as red gram, bengal gram, black gram, sunn-hemp, daincha and groundnut, have a means of utilising the free atmospheric nitrogen through their roots. This capacity of these plants is known to our farmers since a long time, because they found that these Leguminous crops, after harvest leave the soil richer and more fertile than is the case with other crops like ragi, jowar or

rice which really exhaust the soil. It is for this reason, that these leguminous crops are sown in the soil once in two or three years alternating with other crops. Thus **rotation** of crops is a feature with our farming.

How the leguminous crops leave the soil richer was really puzzling for some time. When these plants are pulled out, the roots bear numerous tubercles or **nodules.** Within these nodules are millions of *bacteroids* of *Rhizobium leguminosearum.* These unicellular organisms generally are present in plenty in the soil. They enter the root hairs and grow like long tubes and reach the cortical tissues of the root. There, they stimulate the active division of the cortical parenchyma. This results in the formation of the nodules. The nodules are particularly rich in nitrogen. The nodule formation is profuse in soils poor in nitrogen. By suitable experiments it is now known that these bacteroids utilise the free nitrogen of atmosphere and fix the same as organic salts in the nodule. The bacteroids derive their food materials from the leguminous plants. In return, when these bacteria die, their body as well as the nitrogenous products fixed by them are utilised by the leguminous plants. Thus, here is another case, where a flowering plant and bacteria live in close association and benefit mutually. This is also a case of **symbiosis.**

In certain tropical Rubiaceae, bacteria *Mycobacterium rubiacearum* are found in the tubercles formed in leaves. These bacteria also fix the free nitrogen of atmosphere in the same way as *Rhizobium leguminosearum.*

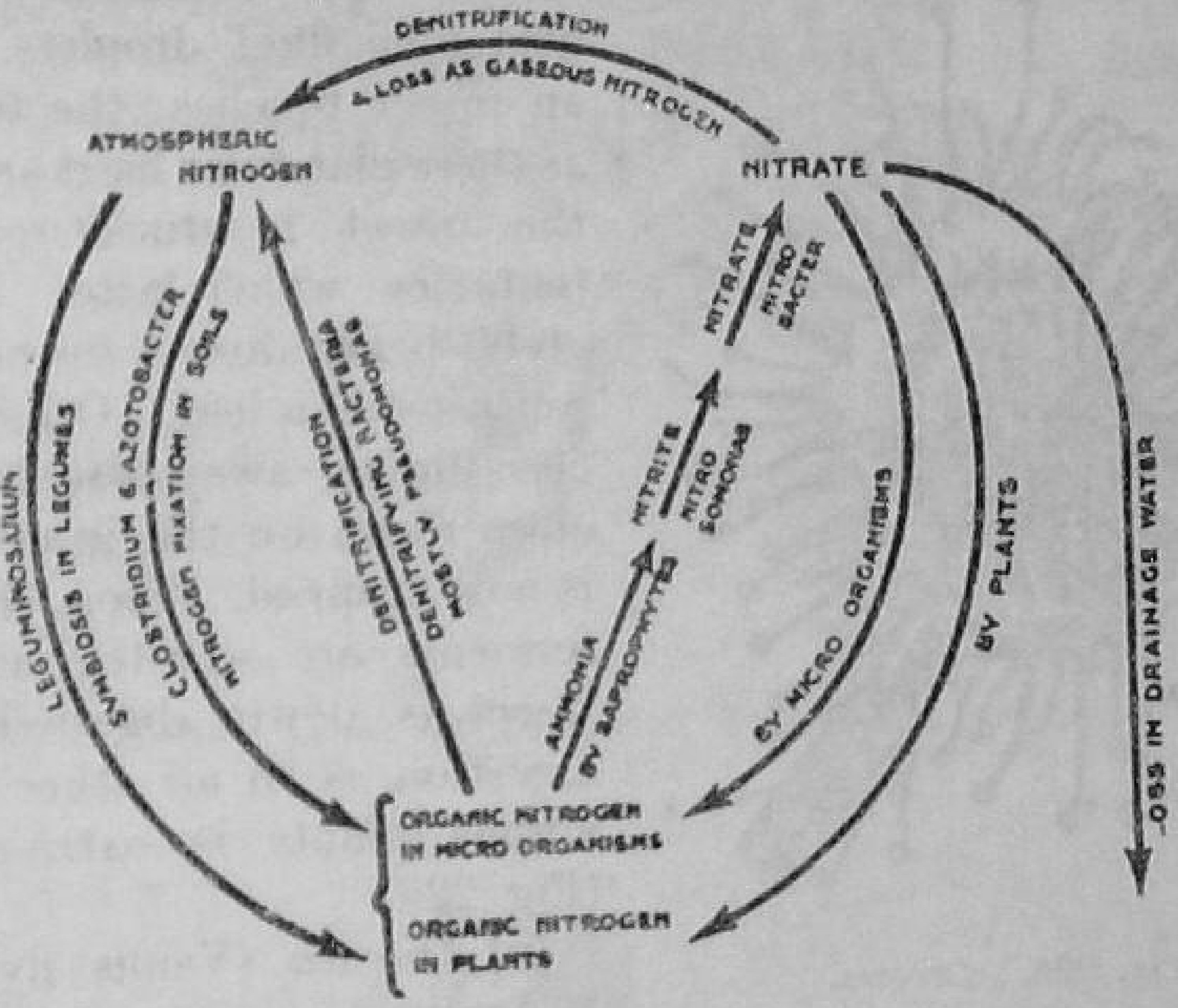
Nitrogen assimilation by bacteria

There are bacteria in the soil which are capable of fixing free Nitrogen of atmosphere. *Clostridium pusteurianum* and *Azotobacter chroococcum* are the two important types in the soil.

There are other bacteria responsible for the formation of nitrates in the soil. Ammonium salts are first converted into nitrites by *Nitrosomonas or Nitrosococcus ;* the nitrites are then converted into nitrates by *Nitrobacter.* The energy set free in the proceeses is utilised for chemosynthesis of carbohydrates.

Loss of nitrogen may also occur through the activity of bacteria belonging to many genera of which *Pseudomonas* is most common. In the presence of an abundance of organic matter and in the absence of oxygen the bacteria are capable of reducing nitrates to nitrites and nitrites to free nitrogen gas. This process is

termed denitrification. The nitrogen cycle may be represented as shown in figure below :—



Special modes of nutrition

Green plants which bear chlorophyll possess the capacity to manufacture carbohydrates taking the carbondioxide of the atmosphere. The carbohydrates are the basic material for the supply of the elements C, H and O and also the required energy for the manufacture of other forms of food. Therefore, plants without chlorophyll and all animals depend directly or indirectly on green plants for their existence.

The special modes of nutrition may be grouped as follows:

1. **Insectivorous plants.**
2. **Saprophytes.**
3. **Parastites.**
4. **Nitrogen assimilation of leguminous plants.**

Insectivorous plants

A few plants adopt the peculiar method of dependence on small insects for their nitrogen metabolism. They are to this extent carnivorous. They catch insects through the devices deve- loped by their modified leaves. They digest them by secreting pepsin hydrochloric acid.

1. *Drosera* (Sun-Dew).—The upper surface of the leaf is covered by glandular hairs which secrete a viscous fluid. The insects are attracted by the glistening fluid droplets. When an insect touches the **tentacles,** as these glandular hairs are called, the insect is stuck up to the tentacles which latter immediately bend down towards the centre of the leaf. Other tentacles further away also bend and close down on the insect which is now trapped. Soon, digestive ferments are secreted and the insect is slowly digested. The digestion as in all other insectivorous plants is extra-cellular. (Fig. 226).

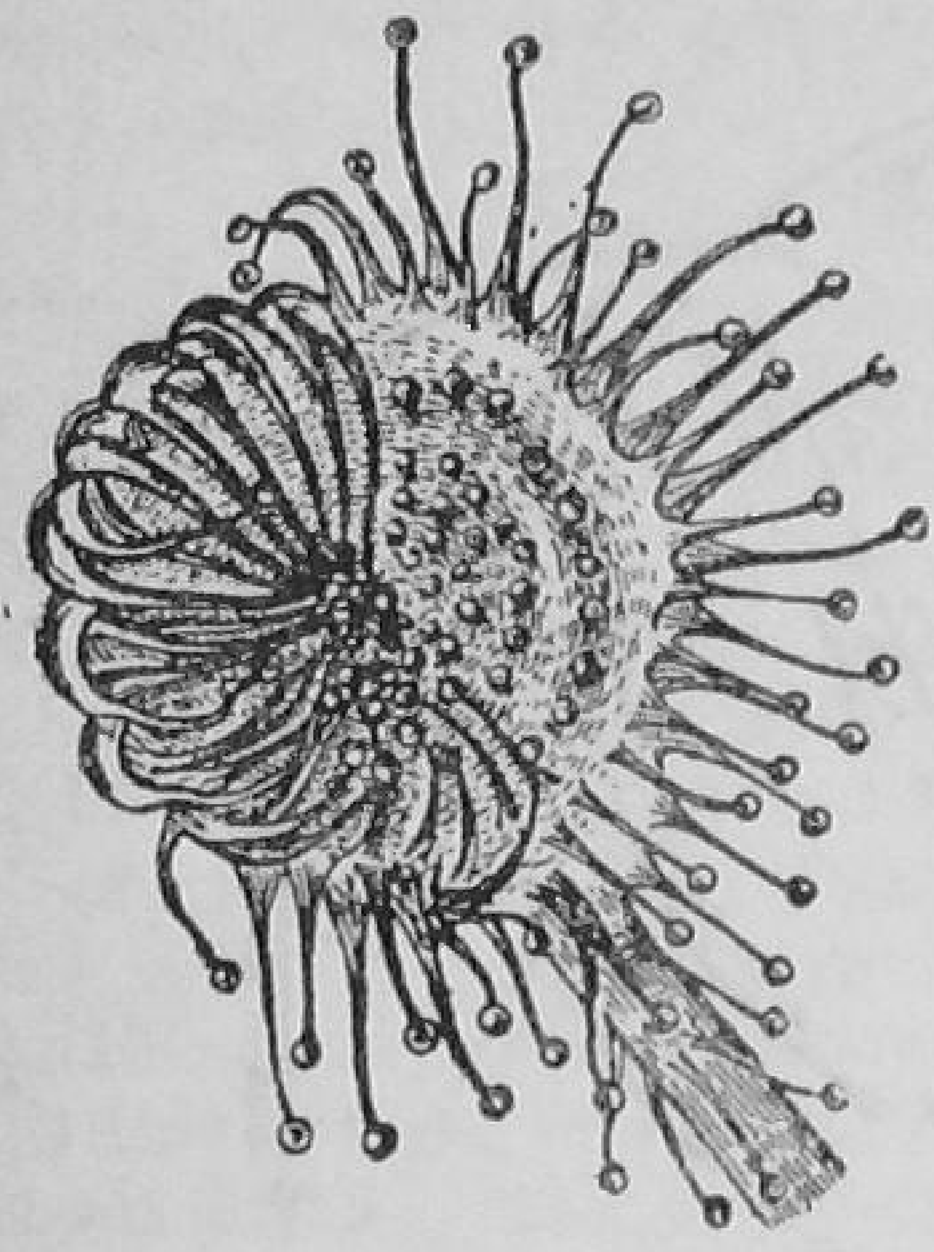


Fig. 226. *Drosera.*

(ii) *Dionœa* (Venus fly trap). It grows in peat bogs. The leaves are two lobed, capable of closing on the mid-rib. There are three sensitive hairs on the upper surface of the leaf; when the hairs are touched by the insects, the two lobes suddenly close

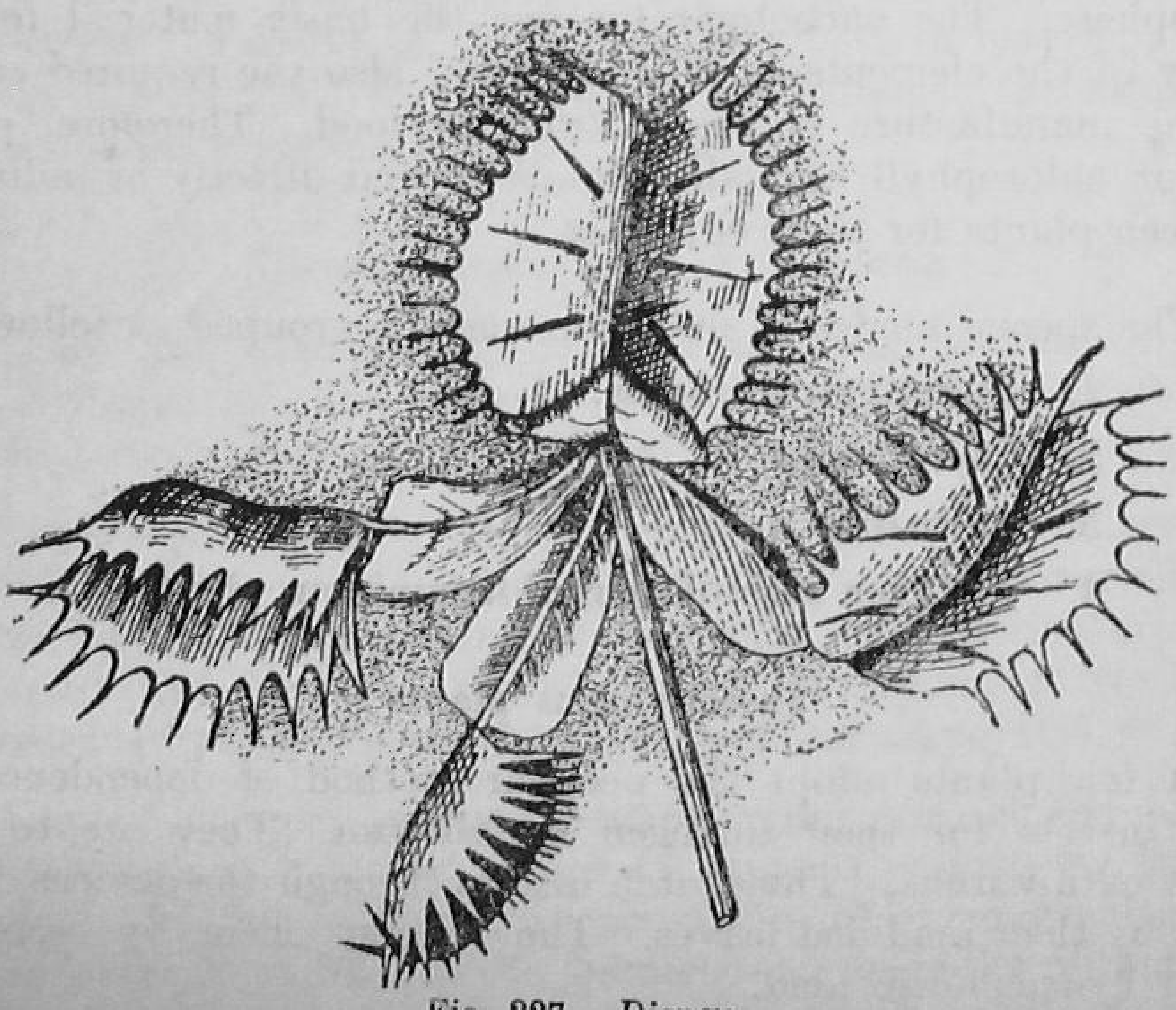


Fig. 227. *Dionœa.*

up, trapping, the insect in between. The leaves hold the insect tightly, secrete digestive juice and when the digestion is completeopen up again. (Fig. 227).

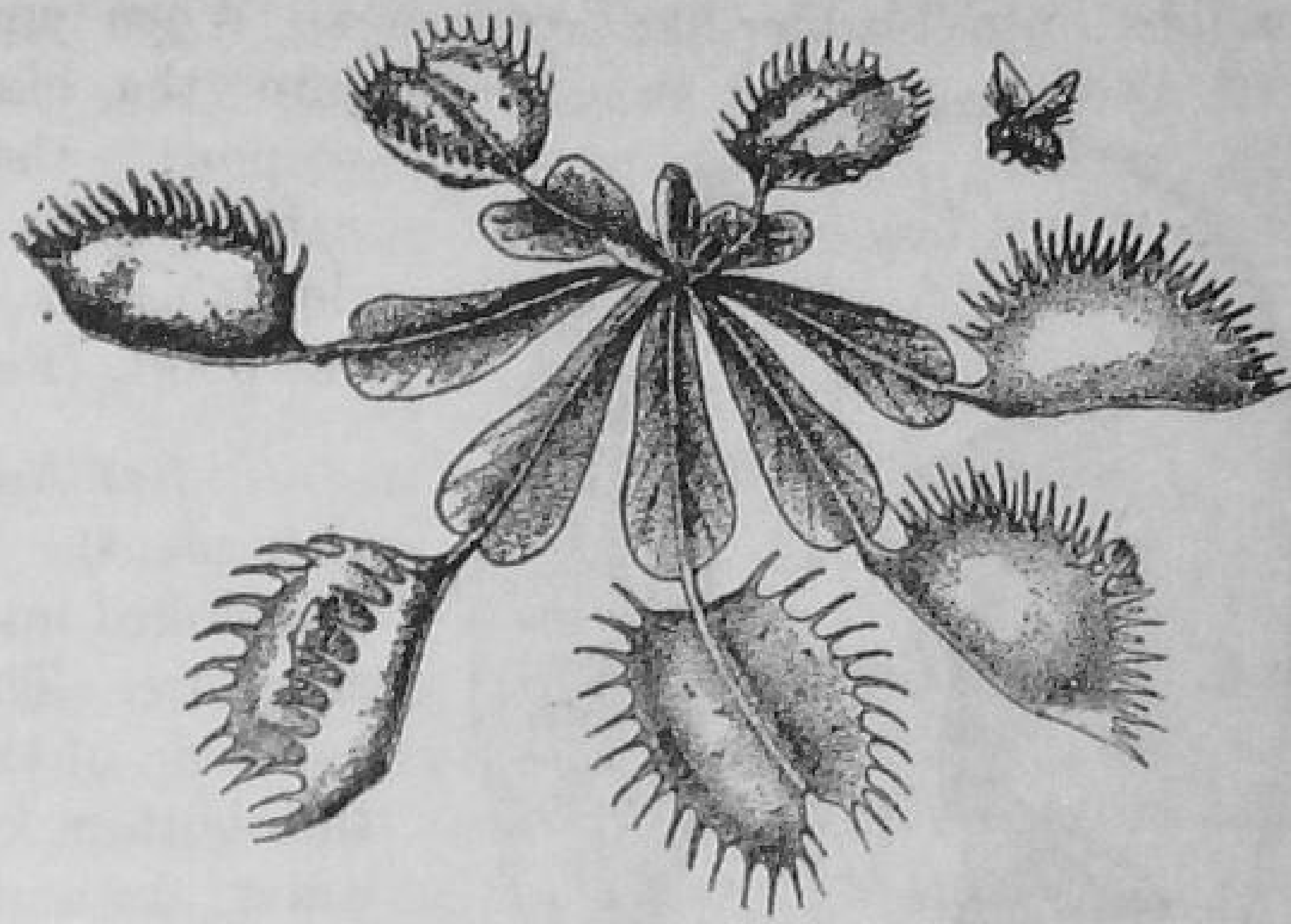


Fig. 228. *Dionæa.* Note the mechanism of the leaf in catching the insects.]

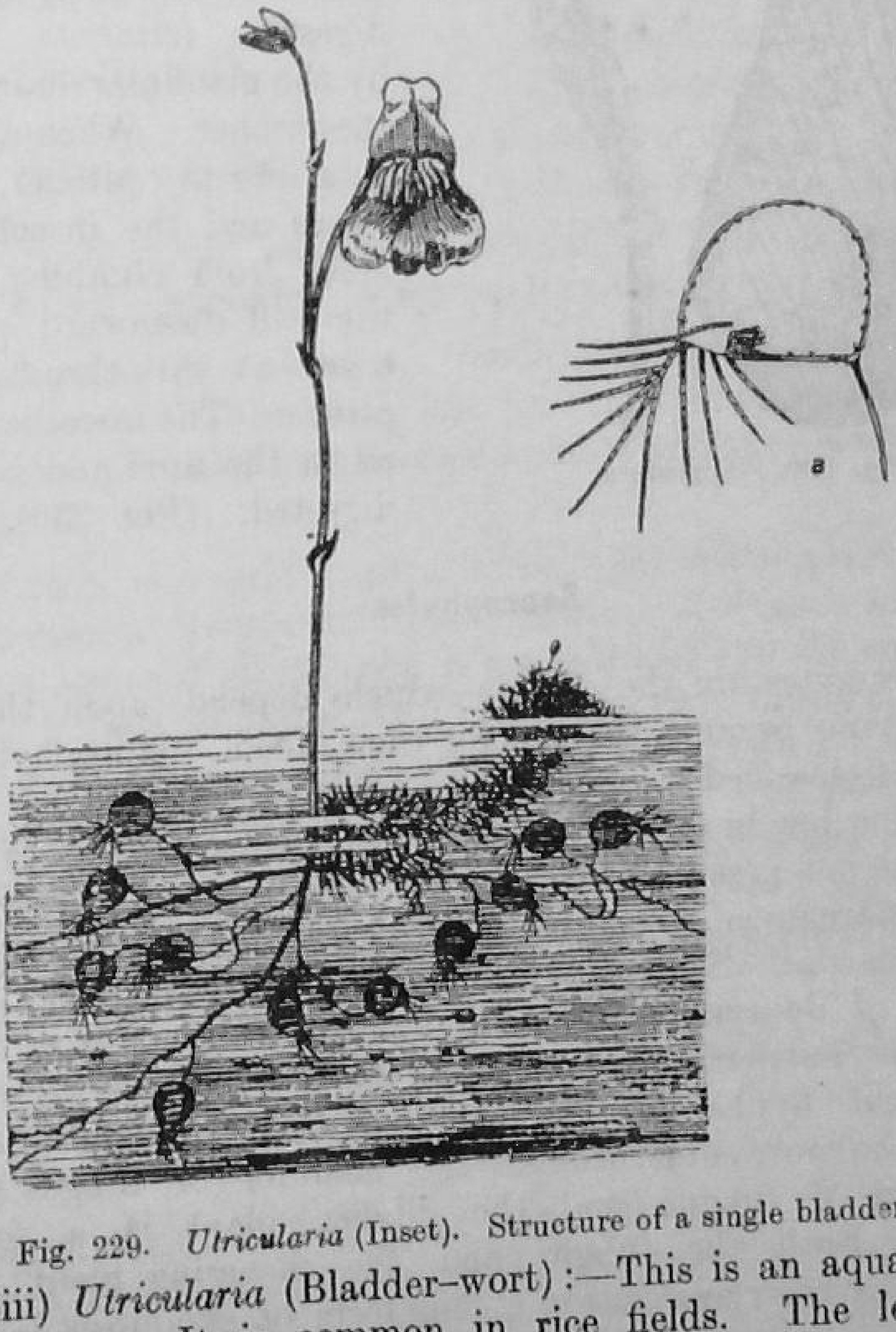


Fig. 229. *Utricularia* (Inset). Structure of a single bladder.

(iii) *Utricularia* (Bladder-wort) :—This is an aquatic plant without roots. It is common in rice fields. The leaves are

modified into bladder-like structures. When small insects get into the bladder they are trapped there and they cannot again come out. The dead insects are digested by the plant. (Fig. 229).

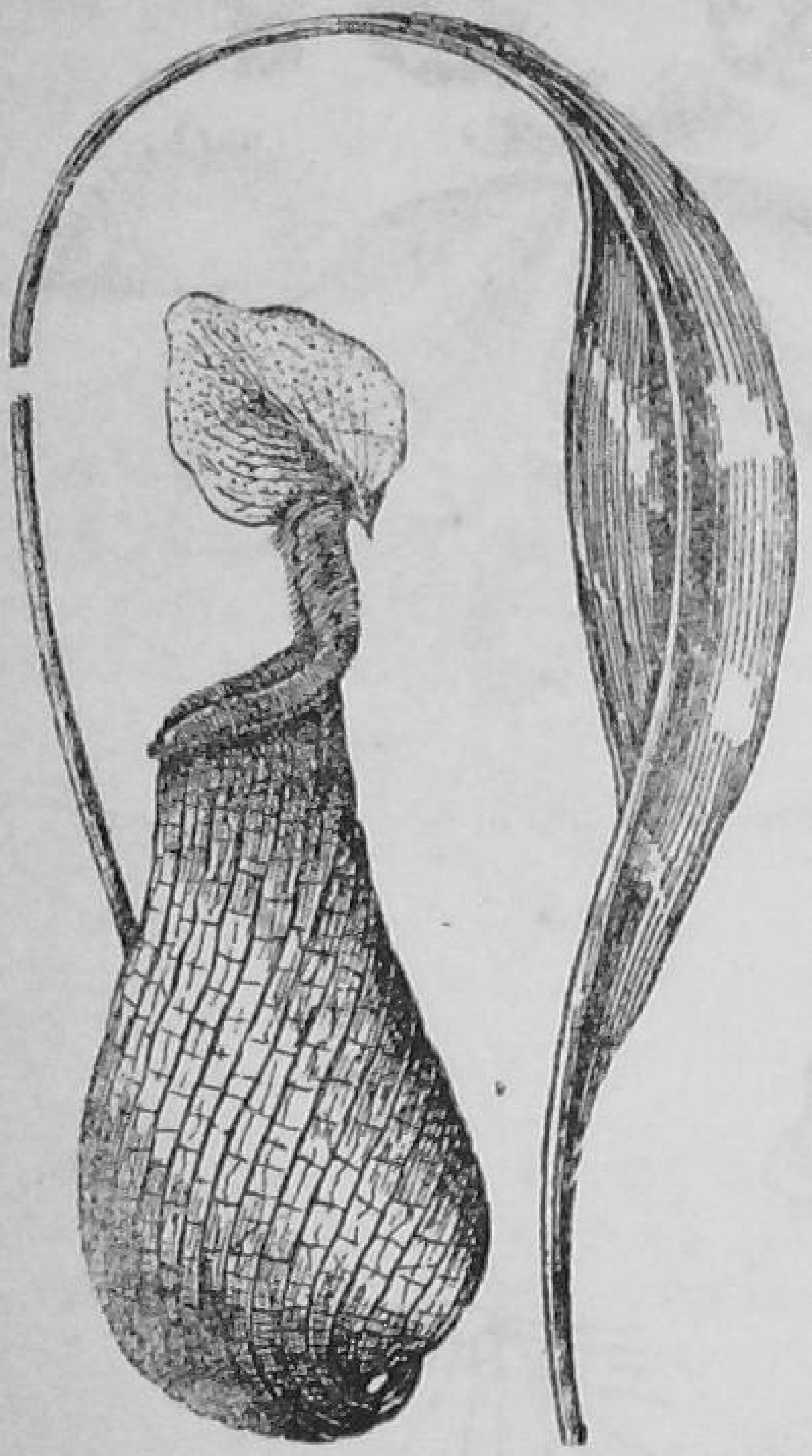


Fig. 230. *Nepenthes.*

(iv) *Nepenthes* :—(Pitcher plant). The leaf blade is modified into a pitcher like structure. There is a lid to one side of the mouth. At the bottom of the pitcher, water accumulates and in this fluid, small insects are found. The fluid contains digestive ferments secreted by the glandular hairs inside the pitcher. When an insect gets into the pitcher, the lid closes and the insect is disabled from climbing up by the stiff downward pointing hairs at the throat of the pitcher. The insect is drowned in the fluid and is slowly digested. (Fig. 230).

Saprophytes

Saprophytes are the plants which depend upon the dead and decaying organic matter for their food. Saprophytes are sometimes classified as partial and complete saprophytes though the dividing line in some cases may not be clear. The total-saprophytes are non-green plants. In the case of partial saprophytes, the plants are green. Among flowering plants, saprophytic habit is only partial. Such plants cannot grow luxuriantly in the absence of decaying organic matter. Normal green plants absorb the nutrients through root hairs, but these saprophytes bear fungal hyphæ in thecortex of the root and the root absorbs the nutrients through the medium of fungus. This association of fungus and the higher plant is a form of **symbiosis.** Both the fungus and the flowering plant benefit mutually by their association. This form of symbiosis is termed

endophytic **mycorrhiza.** In the tropical forests, there are plants which grow in the soil rich in humus and these plants bear external mycorrhiza or **ectophytic mycorrhiza.** Plants with mycorrhiza are devoid of root hairs. The fungal hyphae serve the purpose of root hairs.

Fungi which feed on decaying organic matter are also saprophytes, eg., *Psalliota Campesrtis* (Mushroom), Molds etc.,

Parasites

As in the case of saprophytes, parasites also may be total or partial. A total parasite is devoid of chlorophyll and it is attached to the root or stem of the host. A partial parasite bears chlorophyll and is able to assimilate nitrogen but is unable to grow by itself in the soil directly without getting attached to the root or stem of the host. Therefore the parasites may be grouped as:

Total parasite	Root parasite. Stem parasite.
Partial parasite	Root parasite. Stem parasite.

The roots of all parasites are modified into special sucking organs termed—**austoria,** (Singular-Haustorium).

Total parasites:—*Cuscuta*,, *Orobanche* and *Balanophora* are some of the total parasites. The first mentioned two are sometimes serious parasites on cultivated plants and they cause damage to crops.

Orobanche is a serious parasite on solanaceous plants, especially on tobacco. It is a total root parasite. The seeds are minute and when the seed germinates, it gets attached to the root of the host. If it fails to reach the root of the host the seedling dies. In the case of some of these parasites, the seeds do not germinate without the immediate presence of the host. *Orobanche* consists of a short stout base, which is non-green. There are small scale leaves. The entire plant is inconspicuous until it comes to flowering. The floral axis emerges out of the soil bearing beautiful small bluish flowers.

The vascular bundles of the parasite get attached to those of the host so that there is intimate connection between the two. Food is drawn by the parasite through these haustoria.

Cuscuta (Dodder) is a total stem parasite. When the seed germinates, a short root is produced. The shoot elongates rapidly and nutates round in search of a host by the side. When it touches

the host it coils round it and haustoria are produced which penetrate the host. The seminal root dies out soon. If the parasite fails to find a host by the side, it dies down soon.

Rafflesia is a remarkable total phanerogamic parasite. It is a native of Sumatra and Java. The vegetative part of the plant is modified into hyphæ-like bodies which penetrate the host. The only part of the plant outside the soil is the big flower.

Partial parasites:—*Loranthus, Viscum, Striga and Sandal* are some of the partial parasites. *Loranthus* and *Viscum* sometimes cause serious damage to fruit trees like mangoes.

Viscum bears green leaves and as such is able to assimilate carbondioxide. It gets attached to the host in one point on the stem. The haustorium enters the host and may branch out in different directions along the cambium. The vascular elements of the host and parasite are intimately connected with one another and the parasite is dependent on the host for its water and other esssential elements.

Loranthus attaches itself to the host at more than one point on the host. It also bears green leaves and can assimilate carbondioxide.

Striga is often a serious parasite on *Sorghum* crop. It seeds profusely-as many as 60,000 seeds are produced by a plant. It gets attached to the root of the host.

Sandal-wood tree is also a partial parasite. The roots of this tree attach themselves to the roots of other trees nearby. The tree is a partial parasite.

4. Nitrogen assimilation by leguminous plants has been already discussed.

CHAPTER XXII.

RESERVE FOOD OF PLANTS

Metabolism

Both plants and animals use the same kind of material as food, but plants differ from animals in being able to make these substances from simple substances. The food materials serve primarily for the construction of the new substance of the plant and for the growth of new cells. The nutritive material it must be remembered, is useful to the plant only after it has undergone various chemical changes. The chemical changes occurring in plants constitute **metabolism.** Some of these changes tend towards increase of material and they *constitute constructive metabolism or Anabolism.* In plants certain chemical processes involve the breaking down of materials contained in the protoplasm itself. These necessarily lead to the loss of material and hence they are called **destructive metabolism** or **Katabolism.**

Stored food

Photosynthesis being a rapid process, large quantities of food material will be formed in plants. Since the quantity of material actually utilised by the plant in the formation of new tissues and in the repair of protoplasm is very small, accumulation of material is inevitable. The surplus food material is then stored for future use in various parts of the plant body. Any parenchymatous tissue may serve this purpose, and this tissue is abundant in both roots and stems. Reserve material in the form of starch is present in the medulla, the xylem parenchyma, the medullary rays and the rind of trees.

The storage of food material is undoubtedly of very great advantage to plants, because the demand for food is not the same at all times. Growing points which need material for their growth are far away from the place of storage or production. The photosynthetic activity, and the process of growth do not occur together. Sometimes the process of photosynthesis may be at a standstill and yet the need for food may be very great. For example, deciduous trees flushing forth in spring need large amounts of material for the formation of new leaves and branches. For the growth of these organs, trees have to use the stored reserve material, e.g., *Delonix regia* and the margosa.

The reserve material consists of the three main types, namely, the **carbohydrates,** the fats and the **nitrogenous** substances.

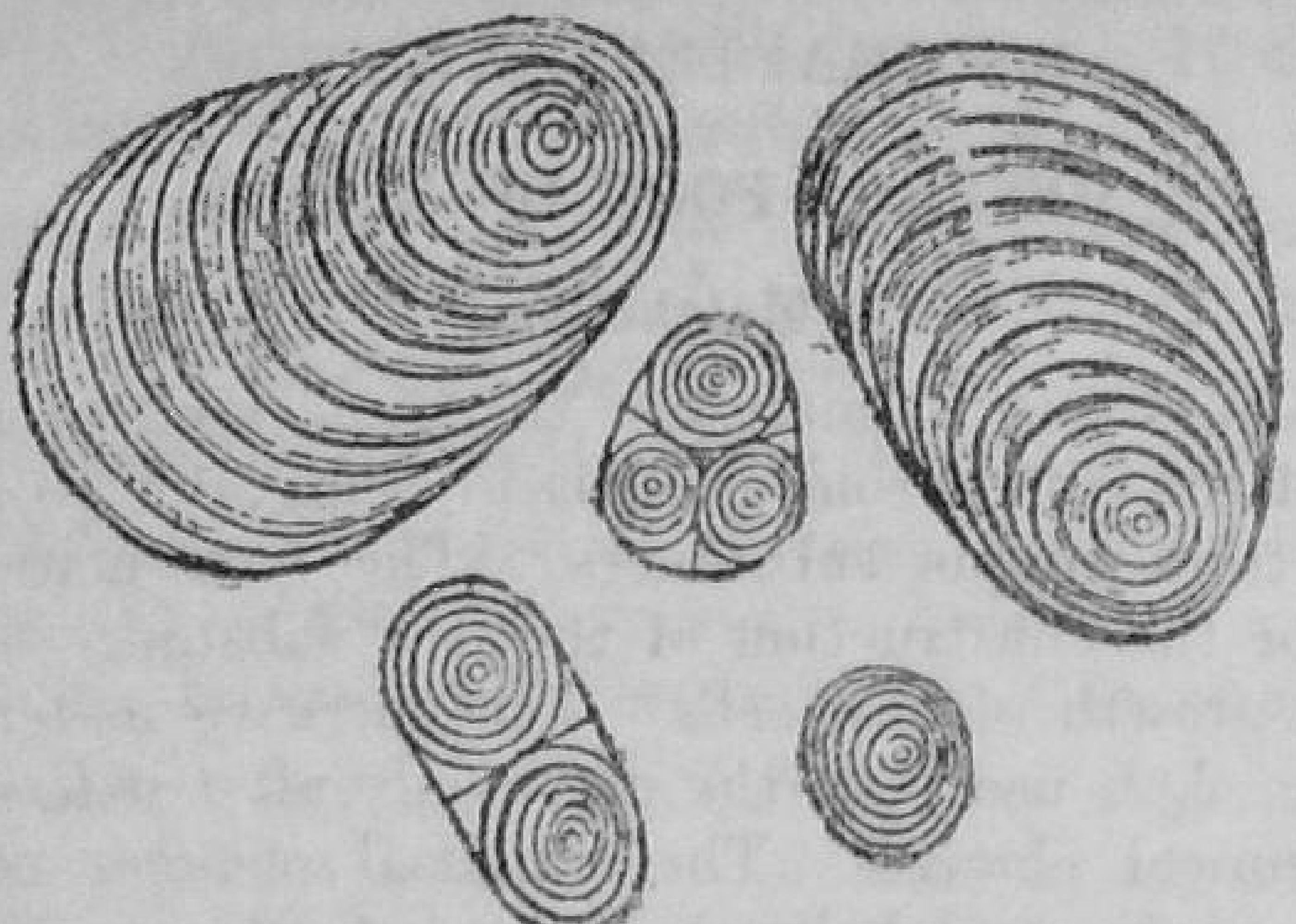


Fig. 231. Starch grains.

Carbohydrates

Starch is undoubtedly the most common and one of the most important of the reserve materials in plants. We find starch grains in most parts of plants, and they are especially abundant in seeds, tubers and rhizomes. The food value of seeds, tubers, rhizomes and corms depends upon the amount of starch contained in them. Starch grains formed in the leaves are very small, but the grains of reserve starch are generally larger. As regards shape and size there is considerable variation. Reserve starch grains are striated, the laminations varying according to the plants. The starch grains in the seeds of *Dolichos Lablab* have concentric striations and they are eccentric in potato (See Fig. 231).

Just as starch grains found in chloroplasts are formed from sugar, so even reserve starch grains are formed from sugar, and leucoplasts are concerned in this transformation.

Although glucose and fructose are almost always found in living cells, they do not occur in large quantities. The only sugar that is found in large quantities as storage product is **cane-sugar or saccharose.** As examples we may mention sugarcane, the beetroot and some of the palms.

Reserve carbohydrate occurs as **hemicellulose** in the seeds of coffee and date palms. The excessive thickening of the cell walls of the endosperm in these is due to the deposition of hemicellulose. In some plants of the Compositae the carbohydrate occurs as **inulin.** The bulbs of Jerusalem artichoke *Helianthus tuberosus,* contain inulin.

Fats and oils.

In many seeds the reserve stuff takes the form of fat or oil and these seeds are of very great economic importance. Oil exists in the form of fine drops, diffused in the protoplasm of the cells of endosperm or cotyledons.

Nitrogenous substances.

Proteins occur in all seeds. In some they are in the form of amorphous particles or in the form of a network. Sometimes they assume regular shapes as in castor and gingelly seeds, and then they are called **aleurone grains.** In grains of cereal plants protein exists as an aleurone layer, the first layer of the endosperm. It must not be supposed that the different kinds of reserve material occur separately. They always occur associated together although one form may predominate.

Enzymes

As already remarked the reserve material is stored far away from the growing points and other younger parts in which growth is active. Carbohydrates and nitrogenous food material have to be translocated to places of storage from the places of production in the first instance, and then later on from there to the parts where growth is active. Generally food materials are stored in insoluble forms and as such they cannot pass from cell to cell. Therefore they have to be rendered soluble before they could diffuse. This transformation of an insoluble substance into a soluble one and of an indiffusible one into a diffusible one is called **digestion.** The changes characteristic of digestion result in the breaking of compounds into simpler substances. The agents concerned in this process are **enzymes,** of which there are many in plants.

Starch has to be broken down in order to allow of its translocation and this change is brought about by the enzyme **diastase.** By hydrolysis caused by diastase starch is converted into maltose according to the formula.

$$\underset{\text{starch}}{2\,(C_6\,H_{10}\,O_5)\,n} + \underset{\text{water}}{n\,H_2O} \longrightarrow \underset{\text{maltose or sucrose.}}{n\,(C_{12}\,H_{22}\,O_{11})}$$

Diastase is widely distributed in plants and it is found in the leaves, in germinating seeds and other places where starch is stored. There seem to be two distinct kinds of diastase, one corroding the grains in an irregular manner from outside, so that the grain loses its usual shape, and the other dissolving the grain

evenly and uniformly, so that the shape is not affected, though there may be a decrease in size. **Invertase** is the enzyme which changes the cane sugar into glucose and fructose. This is evident by the formulae :—

$$C_{12}\,H_{22}\,O_{11} + H_2\,O \longrightarrow C_6\,H_{12}\,O_6 + {}_6C\,H_{12}\,O_6$$
$$\text{sucrose} \qquad \text{water} \qquad \text{glucose + fructose.}$$

Maltose is changed into glucose by **maltase** and the sugar inulin is converted into fructose by **inulase.** The enzyme that attacks hemicellulose and converts it into sugar is **cytase.**

Fats and oils get split into fatty acids and glycerine by **lipase.** **Tryptic** enzymes act on proteids in rendering them soluble.

Translocation

All the food materials that are formed in the leaves are transported either to places where they are needed for use, or to places of storage. The carbohydrates like starch are insoluble. These insoluble food materials are again rendered soluble by the action of enzymes. Even soluble food materials may be converted to simpler forms by the action of enzymes. This process is termed digestion. During the day time much of carbohydrate material is manufactured in the leaves, as the photosynthetic process goes on actively. But during the night this process cannot go on. So if there is any translocation of carbohydrate from the leaves, we should expect to find less amount of starch in the leaves or practically nil of it early before sunrise than what is found at evening before sunset. As a matter of fact a leaf plucked before sunset contains plenty of starch while a leaf detached before sunrise less, as may be demonstrated by placing these leaves in iodine solution after bleaching them with alcohol.

Storage organs

Different parts of plants may serve as storage organs. Some of them are indicated below :—

(i) **Fleshy roots.**—Radish, beetroot, Tapioca, Carrot and other root tubers store reserve food.

(ii) **Underground stems.**—Rhizomes, bulbs, corms and tubers are storage organs.

(iii) **Succulent stems.**—In prickly pear, *Euphorbia tirucalli* and other succulent stems and cladodes food is stored.

(iv) **Fleshy leaves.**—The fleshy leaves of Agave and onion serve as storage organs. In the case of many

xerophytes, fleshy leaves serve as organs of storage especially for water.

(v) **Fruits and seeds.**—In many cases, large quantities of food materials are stored in fruits and seeds. These are the main sources of food for most of the animals including man. In the case of seeds, it has been pointed out that the stored food may be in the endosperm or cotyledon.

(vi) All living cells of plants contain smaller or larger amounts of reserve food in them. In young stems in thin walled parenchymatous cells of pith, medullary ray and cortex, reserve food materials are often stored.

Path of translocation

The carbohydrates and nitrogenous substances formed in the cells of leaves diffuse into the parenchymatous cells surrounding the veinlets. And from these they pass on to the veins through the veinlets. Since the veins join the midrib of the leaf, food material will pass through the midrib into the petiole and thence into the stem. The fact that food materials actually pass through the veins is easy to prove. If in a palmately lobed leaf we cut one of the main veins in the evening and detach the leaf in the morning and test it for starch, we would find plenty of starch in the lobe into which the severed vein runs, and in the other lobes the amount of starch would be very much less or there may be none.

As soon as the food material reaches the stem, it may pass up or down, or in both directions. Since the food material travels through the veins of the leaves and then through the vascular bundles of the petiole and stem, it is obvious that it must travel through the xylem or phloem. We have evidence that the tracheal tissues of the xylem and the sieve tubes of the phloem carry the raw materials for the shoot and the root respectively. The xylem vessels are particularly well adapted for a rapid movement of water. But the great portion of the food material passes through the phloem, and in fact it is the high way for the vertical passage of food through the stem. The sieve tubes contain plenty of carbohydrates, proteids and amides. If the continuity of the phloem is wholly interrupted by girdling a stem all round, down to the wood, it will be seen that growth is slow or absent below the girdle. A cutting, with its bark completely girdled at the lower end, placed in water or soil produces adventitious roots in abundance

above the decorticated portion and, in the part below, few or none appear. In the case of plants having bicollateral vascular bundles, removal of the bark would interrupt only the external phloem, and the inner strands of the phloem would be intact and food would pass all right.

Besides the vertical transmission of food through the vascular bundles, there may also be translocation in the radial direction especially through the medullary rays. In this case the passage may be for storage or for the removal of stored foodstuff. The intimate connection of the medullary rays with the cells of the xylem on one side and with those of the phloem on the other and their large number make them efficient organs, not only for storage but also for radial translocation.

CHAPTER XXIII

RESPIRATION IN PLANTS

Respiration

All plants are continuously at work from the beginning of their life until their death. The performance of their vital function is dependent upon a continuous supply of oxygen and, if this supply is cut off, all activities cease, and unless oxygen is supplied within a reasonable time they die. This intimate relationship existing between the supply of oxygen and the vital functions gives us a clue to the source of energy which plants need for performing their work. Although large quantities of the organic material produced by higher plants are used for the construction of new cells and storage, a portion of this material is broken down into simpler organic compounds for the supply of energy. This process of decomposition is called **respiration.** In normal respiration carbon dioxide is produced as well as some amount of water. But this is not of any importance to the plant. The breaking down of organic substances liberates some energy, and this is the energy which plants make use of for their vital functions. Since the driving power in many of the vital phenomena of plants is dependent upon this liberated energy, respiration is essentially an energy releasing process going on continuously in plants.

Respiration should be distinguished from digestion. The process of rendering higher and insoluble forms of food such as starch to simpler and more soluble forms, is termed **digestion. Digestion uses up energy whereas respiration releases energy.**

The release of energy during respiration is not directly in the from of heat. The energy released from the oxidation reduction processes involved in respiration is directly transformed into other forms of chemical energy and after the various physiological processes, if there is any surplus, it appears as heat energy.

Experiment (1) :—Respiration in plants is easily demonstrated by showing that carbon dioxide is evolved by them. Place inside a wide mouthed bottle, a few germinating seeds of *Dolichos Lablab* on pieces of wet blotting paper. Close the mouth of the bottle with a well fitting rubber stopper having two holes. Insert in one of the holes of the cork a thistle funnel tube so that the end of the tube reaches almost the bottom of the bottle. Into the other hole is to be inserted a bent tube so that the end of the tube is on a level with the inner surface of the stopper. Close both the

funnel and the free end of the bent tube so as to prevent the air from getting into the bottle. After the lapse of two or three hours connect the free end of the bent tube with another tube and dip it in a glass vessel containing lime water. Then pour water into the bottle containing seeds. As the air bubbles through, the clear lime water begins to turn turbid and milky. If another set of apparatus prepared similarly but containing dry seeds be tested, no change will be observed in the lime water (Fig. 232).

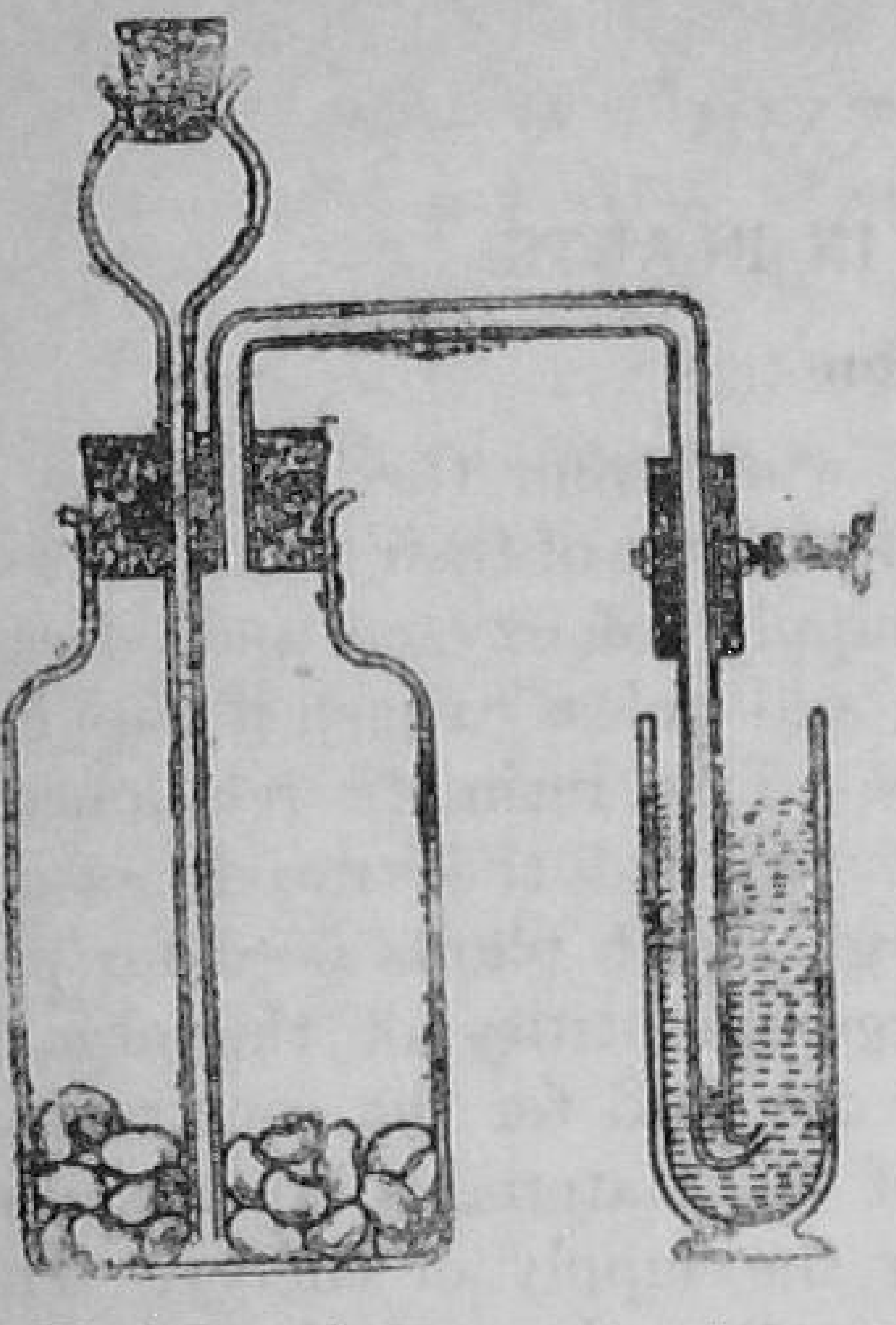


Fig. 232. Apparatus to demonstrate the evolution of CO_2 by germinating seeds.

This milkiness is due to the precipitation of chalk formed by the combination of carbon dioxide with lime water, and it is evident that the carbon dioxide has come from germinating seeds.

(2) **Experiment** :—That germinating seeds give out carbon dioxide even when supplied with air freed from this gas can be easily demonstrated. Place some quantity of germinating seeds of *Dolichos Lablab* in a glass jar or flask fitted with a rubber cork pierced by two holes and fitted with glass tubes. Connect the tube on one side with an aspirator interposing a jar or flask or wash bottle containing baryta or lime water. The other side must be connected with a jar or flask containing lime water and this with a flask having a strong solution of caustic potash and to this a tube fitted containing pumice stones soaked in the same solution. All the connexions made by glass tubes and rubber stoppers must be made perfectly air tight. When water is allowed to flow from the aspirator bottle, air will be drawn in through the bottle containing potash, and all the carbon dioxide in the air will be absorbed by the potash. The air thus deprived of the carbon dioxide will get into the flask containing germinating seeds. The lime or baryta water in the jar between the jar containing germinating seeds and the flask containing potash solution remains perfectly clear, whereas the lime water in the jar containing germinating seeds and the aspirator becomes milky (Fig. 233). After a time the milkiness increases. It is needless to point out that the carbon dioxide has been evolved by the germinating seeds.

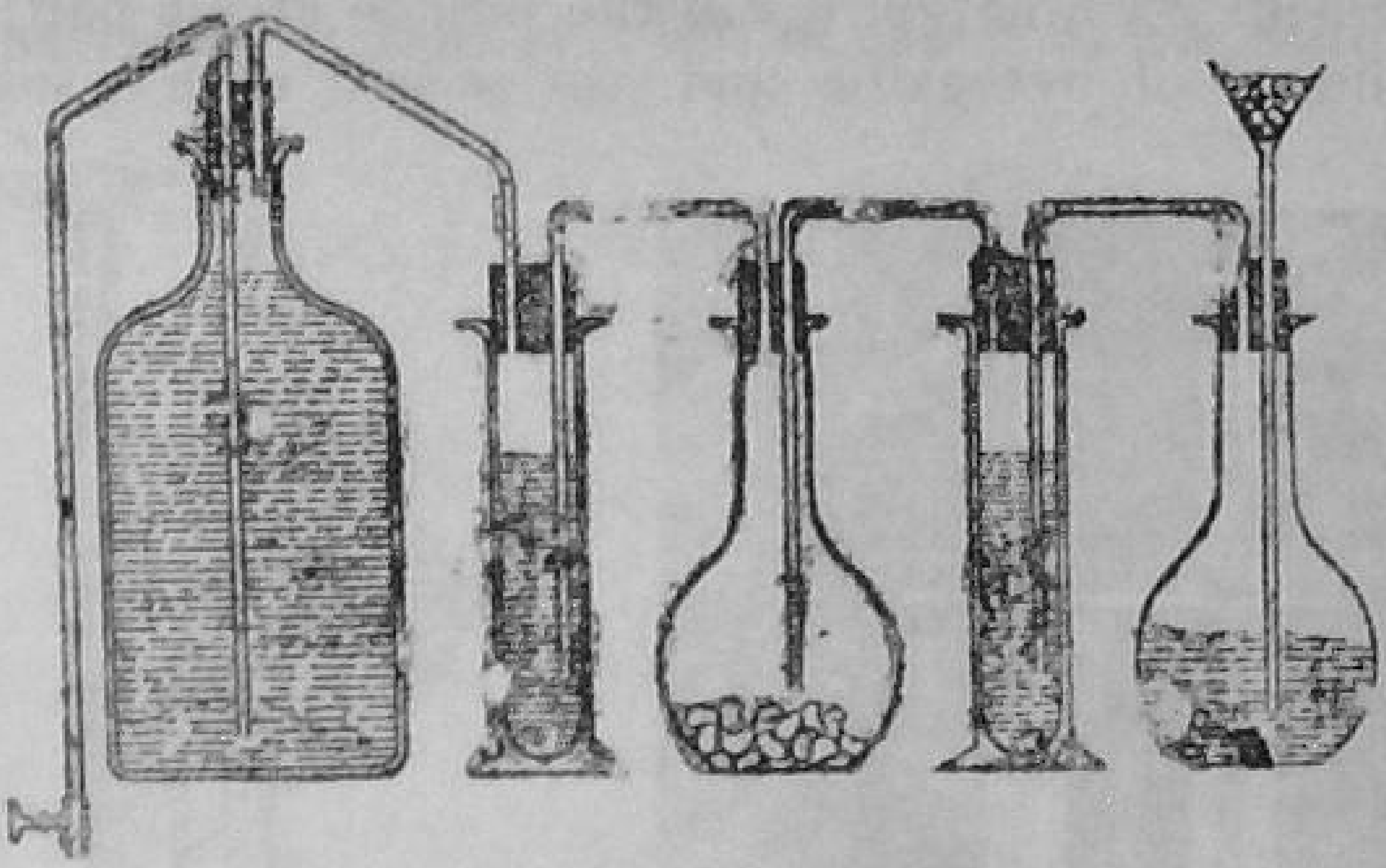


Fig. 233. Apparatus to show that germinating seeds give off carbon dioxide even when air deprived of this gas is supplied.

(3) **Experiment** :—The absorption of oxygen during the respiratory process and its necessity to continue respiration are capable of easy demonstration. For this purpose soaked seeds of *Dolichos Lablab* are very useful. They germinate and develop into seedlings only when oxygen is available, but not when this gas is

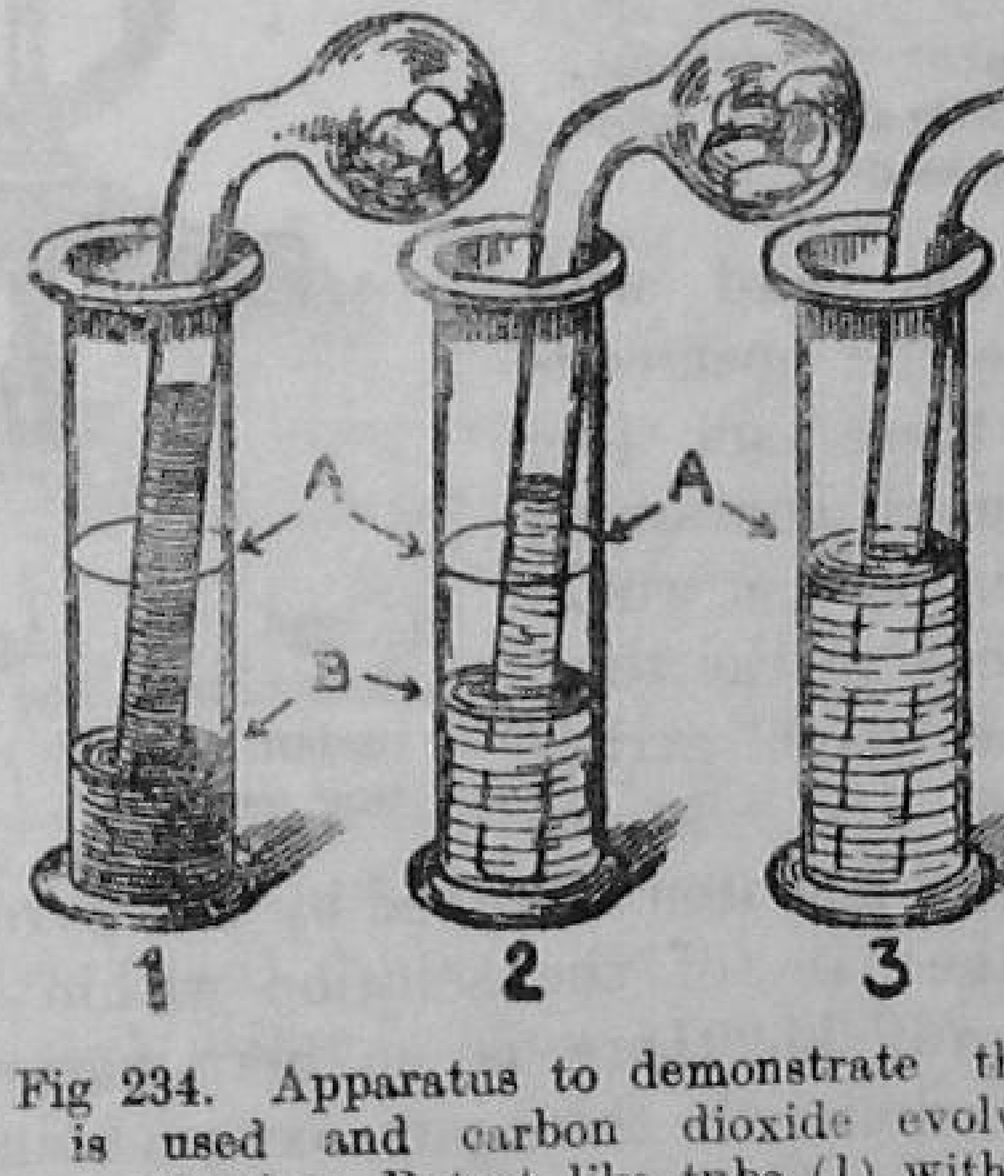


Fig 234. Apparatus to demonstrate that oxygen is used and carbon dioxide evolved during respiration. Retort like tube (1) with Pyrogallic acid solution (2) with caustic potash solution (3) with water only. A : Level of water at the beginning and B at the close of the experiment.

withheld. Secure three retort like tubes (respiroscopes) and three jars. Place five or six soaked seeds of *Dolichos Lablab* in the bulb of each of the three respiroscopes with some cotton or a few pieces of blotting paper moistened with water, so as to keep the seeds moist

enough to help germination. Fill the jars to about half, the first with a solution of pyrogallic acid, the second with a solution of

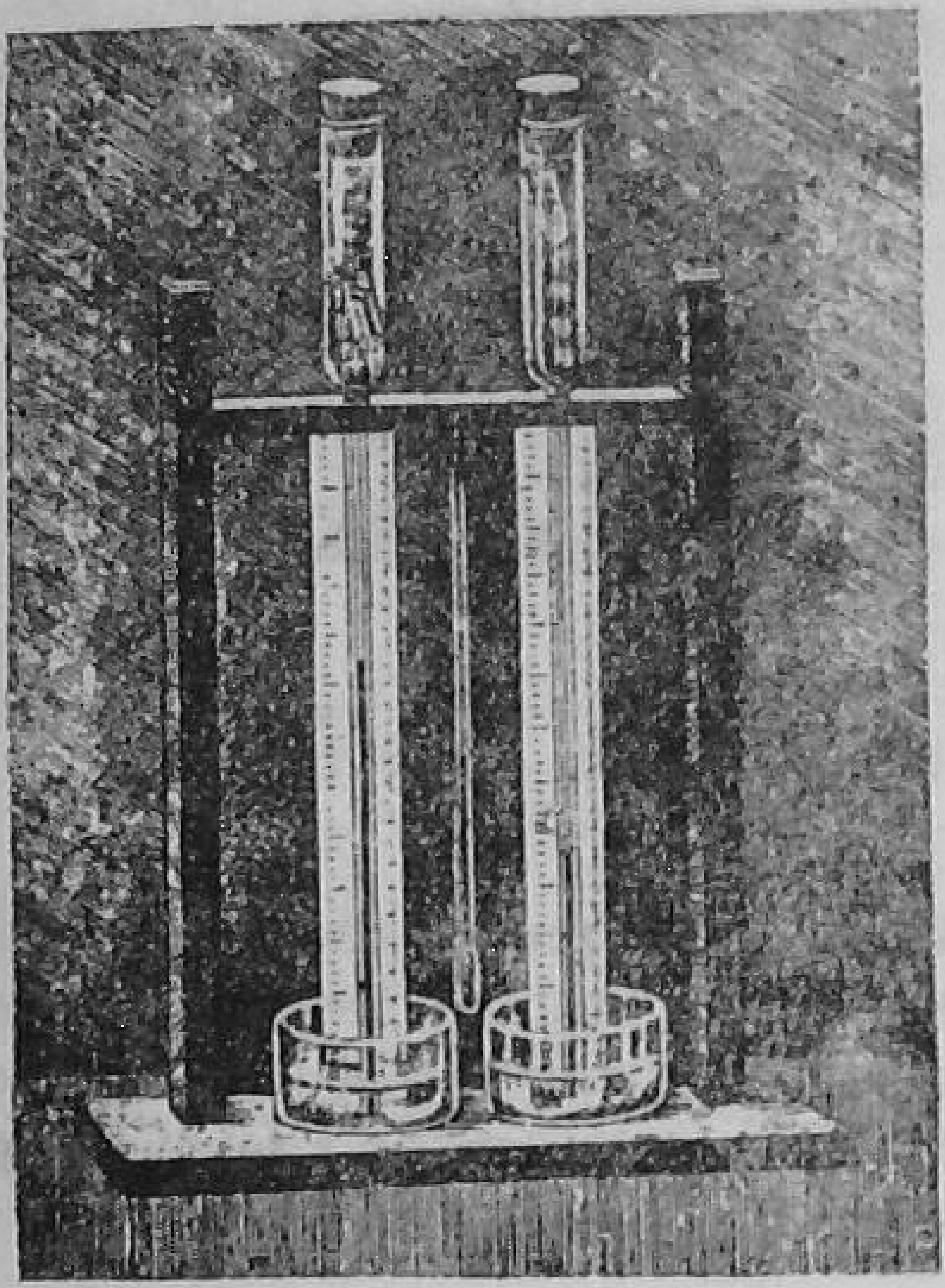


Fig. 235. An experiment to demonstrate the absorption of O_2 and evolution of CO_2 by germinating seeds.

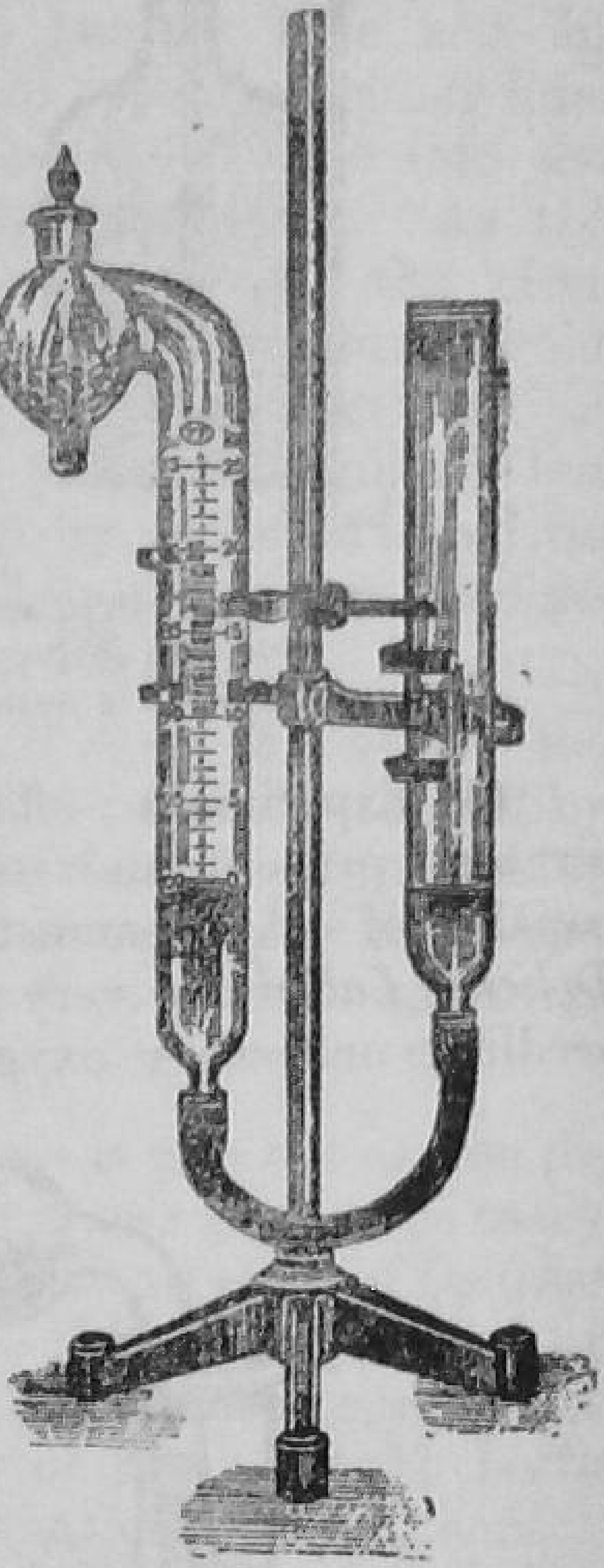


Fig. 236. An Apparatus to demonstrate the evolution of carbon dioxide by germinating seeds.

caustic potash and the third with pure water, and place the open ends of these tubes in these jars (see Fig. 235) If the tubes containing seeds be examined next day, it would be found that the seeds in the third and the second tube have germinated, but not in the first. In the first tube all the oxygen has been absorbed by the pyrogallic acid, and hence, we see the rise of the solution within the tube. Since oxygen is not available there is no germination. On the other hand in the second and the third jars, oxygen being available there is germination. Further, in the second tube the carbon dioxide evolved has been absorbed by the caustic potash solution and hence there is rise of water within the tube, whilst in the third tube there is no change, as the space occupied by oxygen before the experiment has been occupied by the carbon dioxide.

(4) **Experiment for Stomata:**—In all higher plants the entrance of air into the plant is effected through the stomata. This fact admits

of easy proof. That air actually passes out through the stomata can be demonstrated by dipping a leaf of castor in hot water with

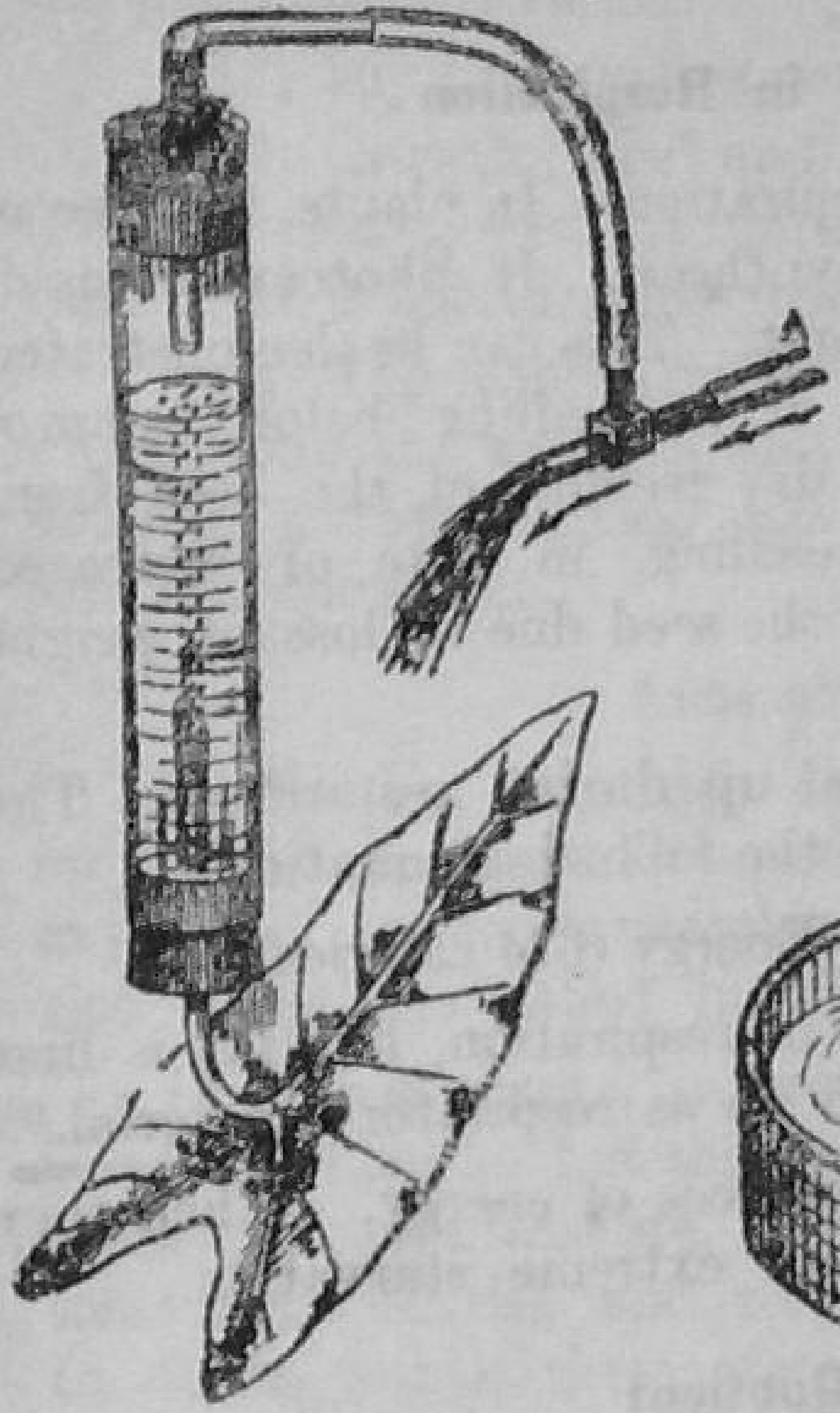


Fig. 237. Apparatus to prove that air passes through the stomata.

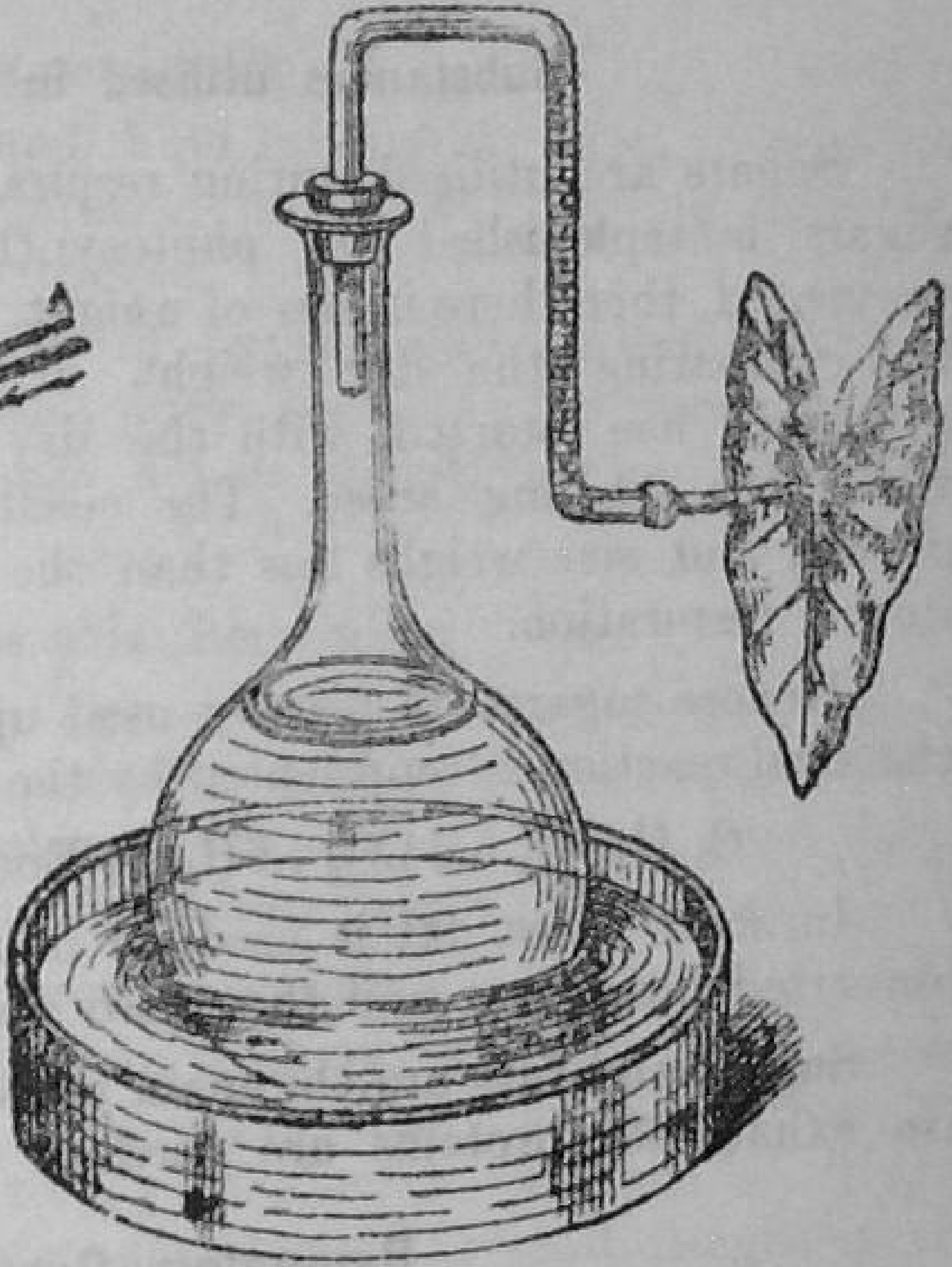


Fig. 238. Apparatus to demonstrate the existence of stomata in the leaves of plants.

the lower side uppermost. When this is done, a number of air bubbles rise from the lower surface of the leaf here and there. The air in the intercellular spaces expands on account of the heat communicated by the temperature of water and it escapes through the stomata. The passage of air from outside into the leaf through the stomata can be inferred from the following two experiments. (i) Insert the petiole of a *Colocasia* leaf at one end of a cylindrical straight glass tube of about a foot long and one inch in diameter fitted with single holed rubber cork to both the ends, and after filling the tube with water to about nine inches, insert a bent tube into the upper cork (see Fig. 237) and suck the air. Then a stream of bubbles rises from the cut end of the petiole. Instead of sucking the air, the tube may be connected with a suction tube attached to a water tap and worked. (ii) Another method of showing the same is by using a flask into which the *Colocasia* leaf is fitted, after filling it with water and inserting the bent tube as shown in Fig. 238. The flask containing water is heated until the water just begins to boil and then it is cooled. At

once a stream of bubbles will be seen to rise through the water in the bent tube from the cut end of the petiole. If the lower surface is vaselined, no bubbles arise.

Substances utilised in Respiration

Sugars are utilised during respiration. In plants, the loss of sugars is replenished by photosynthesis. If photosynthesis is prevented, then there is loss of weight. This can be demonstrated by comparing the dry weight of a seedling before photosynthesis has started, with the dry weight of the seed from which the seedling arose. The seedling, in spite of increased growth and size weighs less than the seed due to loss of weight during respiration.

Hexose sugars are usually used up during respiration. The chemical reaction is represented by the following equation:

$$C_6 H_{12} O_6 6 \rightarrow CO_2 + 6H_2O + \text{Energy (674 calories)}$$

In some cases, fat is used up in respiration, but fat is first converted into sugar and then used up as respiratory material.

Sugars and fats are the main sources of energy. When they are exhausted, proteins are used in extreme starvation.

Respiratory Quotient

The general formula given above shows that the volume of oxygen consumed and that of carbon dioxide evolved, are equal. The ratio (CO_2/O_2) is called respiratory quotient. In typical cases it is equal to 1.0.

When the end product of respiration is not carbon dioxide, but partially oxidised compounds like oxalic acid or tartaric acid, the quantity of carbon dioxide evolved is less than the quantity of oxygen absorbed. In such cases, the respiratory quotient may be as low as 0.7.

When oxygen is deficient in the medium, carbon dioxide may be evolved without oxygen being absorbed. When the respiratory material, such as organic acids, contain more oxygen in their composition, the volume of oxygen absorbed will be less than the volume of carbon dioxide evolved. Under such conditions, the respiratory quotient will be greater than 1.0.

Factors influencing Respiration

(1) Respiration increases with rise in temperature until the latter begins to injure the cells.

(2) Moisture is an important factor. Seeds are air dried to minimise respiration. The effect of moisture in different plants and plant parts is varied.

(3) Injury increases respiration.

(4) Growth, age and kind of tissue affect respiration. During rapid growth, respiration is intense. During dormancy respiration is considerably reduced.

(5) The concentration of oxygen and carbon dioxide in the surrounding medium also affect the rate of respiration. Too much of carbon dioxide may act as anaesthetic and reduce the rate of respiration.

Anaerobic Respiration

Respiration in which oxygen is utilized is termed **aerobic respiration or normal respiration.** Respiration in the absence of oxygen is termed **anaerobic respiration, or fermentation.** It is also sometimes called **intramolecular respiration.**

In higher plants, anaerobic respiration goes on when oxygen is not available, but this cannot supply for long the necessary energy to maintain life. (Fig. 239). Many bacteria, fungi, and some algae flourish and respire even in the absence of oxygen. In other words, these are anaerobic. The yeast fungus is able to thrive as an anaerobic organism when there is abundance of sugar. The requisite energy is obtained by fermentation. The anaerobic respiration or fermentation is represented as follows :--

$$C_6 H_{12} O_6 \longrightarrow 2 CO_2 + 2 C_2 H_5 OH.$$

Carbon dioxide and alcohol are the end products. In the absence of fermentable sugar, yeast respires in the normal way by taking in oxygen. If both sugar and oxygen are available, fermentation as well as respiration goes on simultaneously. The enzyme **zymase** which is present in yeast cells is responsible for the alcoholic fermentation.

Anaerobic respiration is common to many fungi and bacteria. Alcoholic fermentation is confined to few of them. *Bacillus butylicus* is strongly anaerobic and ferments butyl alcohol.

Forms of Respiration

The chief function of respiration is the release of energy. As fermentation accomplishes this, it is a substitute for aerobic respiration. There are some bacteria which have still another substitute for respiration ; they are able to use the energy released in the oxidation of inorganic compounds containing sulphur and

nitrogen. Oxygen is consumed, but the compound acted upon contains no carbon. *Beggiatoa* is one of the best known sulphur bacteria which occurs in spring waters containing hydrogen sulphide which it oxidizes.

$$H_2 S+O \rightarrow S+H_2 O$$

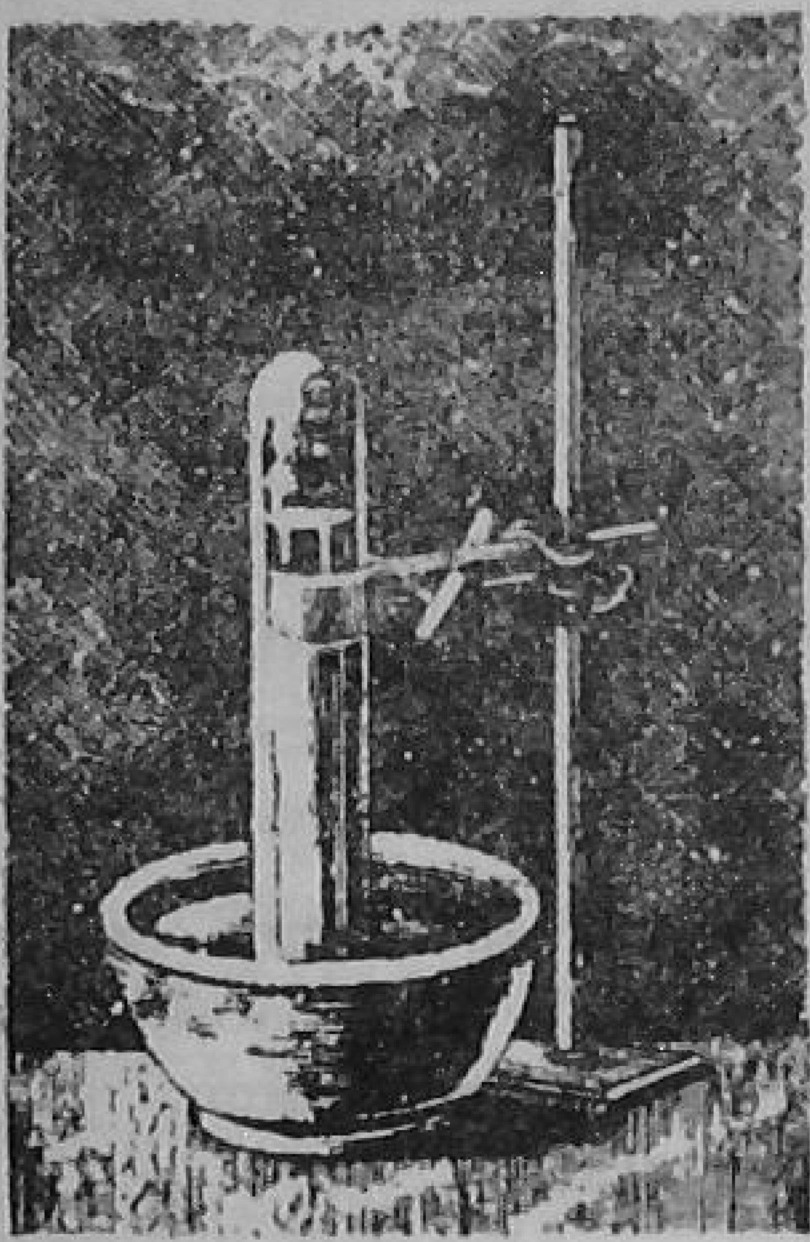


Fig. 239. Apparatus to demonstrate that respiration goes on for a short time even in the absence of oxygen.

Sulphur is found in granules within the bacteria. *Beggiatoa* dies off rapidly when supplied only with a substratum of organic matter. But if water containing hydrogen sulphide is supplied it is able to grow. There are the so-called **iron bacteria** which are capable of converting ferrous into ferric oxide. In the case of the nitrification bacteria already considered under soils, the compounds used are not carbohydrates but complex nitrogen containing compounds. Whether carbon dioxide is released as in ordinary aerobic respiration or whether it is not released as in the conversion of the alcohol of fermentation into acetic acid ($C_2 H_5 OH+O_2 \rightarrow C_2 H_4 O_2+H_2 O$) or whether oxygen is used up as in ordinary respiration, or not used as in fermentation (anaerobic respiration) the fact remains clear that **in all these cases there is the release of energy.** In essential, respiration is only this.

Both plants and animals respire, and so, we should expect the carbon dioxide to accumulate in the atmosphere. If this influx of carbon dioxide is not checked, it is obvious that the surface of our planet will soon cease to have living organisms. But in nature, in spite of the universal katabolism going on in the form of respiration, the atmosphere never becomes foul. This forces us to the conclusion that there must be some other process going on in nature which prevents the accumulation of carbon dioxide in the atmosphere. Plants having chloroplasts take up carbon dioxide and evolve oxygen, as long as there is sunlight. The air rendered foul by the breathing of plants and animals, is thus made pure by green plants.

Oxidation and Reduction

Since oxygen is absorbed during respiration it is commonly spoken of as a process of combustion. The absorption of oxygen

and the production of carbon dioxide and water as end products in both respiration and ordinary combustion lend support to this view. But the supply of pure oxygen does not lead to the acceleration of respiration nor does the absence of oxygen immediately stop the process. So respiration cannot be considered to be process of combustion fully. Further for pure oxidation high temperature is necessary and this does not exist in plants. In plants during respiration a certain amount of heat is produced. It is not perceptible, because it is conducted away as soon as it is produced through the large extent of surface which plants possess. However, in parts of plants where growth is actively going on, there will be a distinct rise in temperature, if rapid conduction is prevented. Flowers of some species of *Aroideae* show a rise of several degrees at the time of blossoming. The rise of temperature during respiration may be readily demonstrated in the case of flowers or germinating seeds. (Fig. 240). Fill two thermosflasks, one with germinating seeds and the other with killed seeds. Insert thermometers so that their bulbs are in the midst of flowers or seeds. After some hours the thermometer in the germinating seeds will show a rise of 2 or 3 degrees over and above the one in killed seeds.

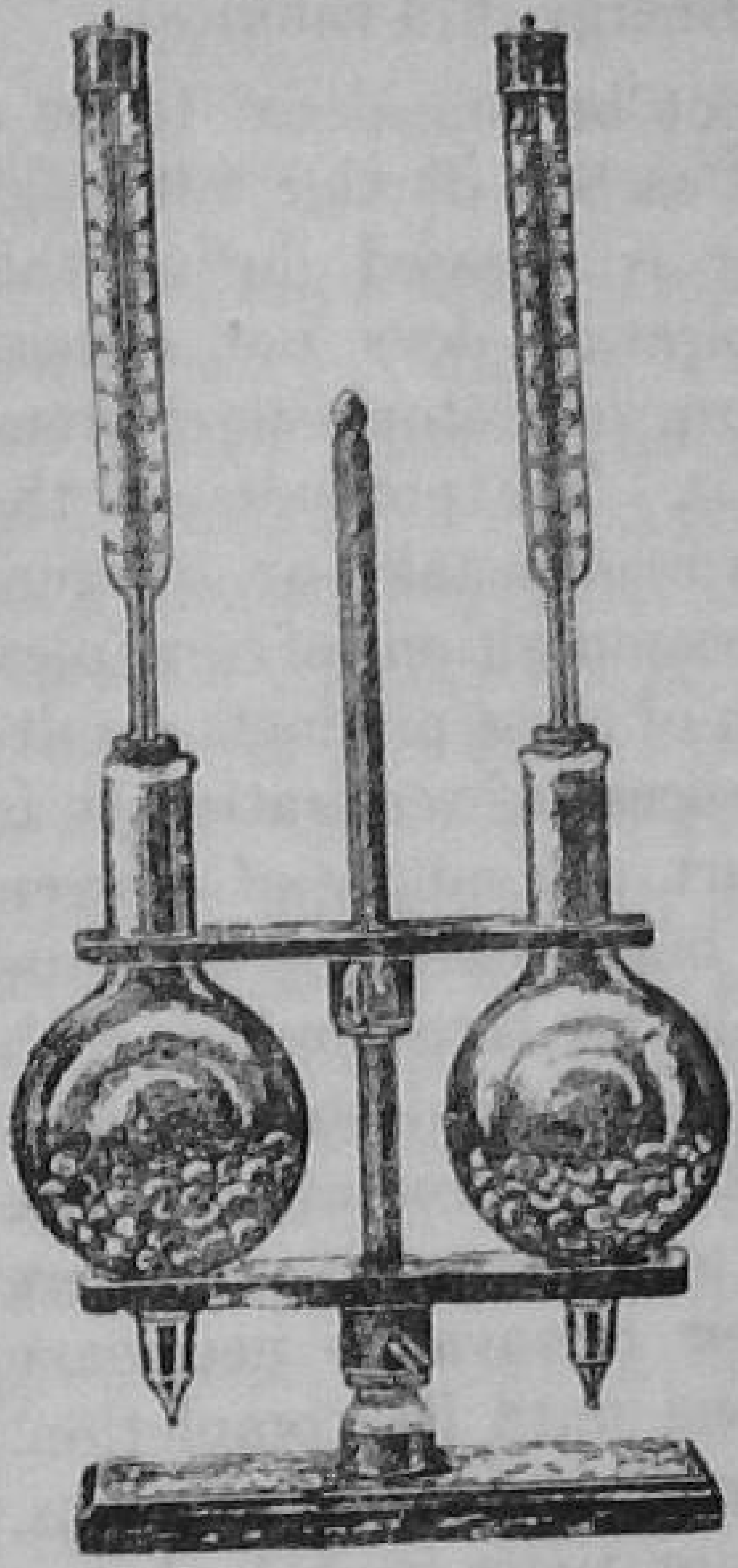


Fig. 240. Apparatus to demonstrate the rise in temperature due to active respiration.

Oxidation means the addition of oxygen or the removal of hydrogen. The reverse process, *viz.*, the addition of hydrogen or the removal of oxygen is **reduction.**

Oxidation—reduction systems in living cells play an important role in respiration. Through these systems, chemical energy is directly transferred to other physiological process in the cell without being wasted in the form of heat.

The Mechanism of Respiration

The volume of oxygen taken in and the volume of carbon-dioxide given off by higher plants under normal conditions are about equal. But the carbon dioxide produced is not always equal in volume to the oxygen which disappears. The respiratory

process, if we take into consideration only the end products, may be expresed, as a chemical equation thus :—

$$C_6 H_{12} O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{Energy (674 calories)}.$$

The process of respiration should not be considered to be a mere exchange of the gases, oxygen and carbon dioxide, although the former is consumed and the latter is released during this process. The essential feature of respiration does not consist in an oxidation process but in a breakdown of protoplasm or some of the organic substances contained in it. The products of the decomposition of the organic substances readily take up oxygen. Respiration thus involves first the decomposition of complex organic substances and then the oxidation of these products resulting from the breaking down. In the process of respiration it is believed that enzymes play a distinct part. A supply of oxygen is undoubtedly essential for the process, but it does not combine directly with carbon compounds. Its chief use is to combine with and remove the substances formed by the breaking down of protoplasm or proteins, so as to prevent their accumulation. The presence of these secondary products may seriously interfere with the process of respiration. So their removal is necessary to facilitate the continuance of the process until its completion. The carbohydrates are mostly used up in the repair of proteins. It is also likely that in some cases and at times carbohydrates also may be utilised for the release of energy by chemical decomposition, but even then not by direct oxidation.

Respiration is a complex process and the equation $C_6 H_{12} O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O_2$ tells very little of the complexity of the series of processes. There are catalytic mechanisms in the cell which activate oxygen. An iron compound was supposed (by Warburg) to act as oxygen activator. The hydrogen of the sugars was also supposed (by Wieland) to be activated by the enzymes dehydrases. A third compound, **Cytochrome** is believed to act as a **carrier.** It brings into reaction the activated oxygen and the activated hydrogen. It is now believed that **glutathione, cytochrome** and **flavoprotein** (the yellow pigmented enzyme) are the important carriers of respiration. Respiratory mechanism may take more than one path.

Blackman represents respiratory mechanism as consisting of four phases :—

(1) Hydrolysis of carbohydrates to hexoses.

(2) Activation of normal hexoses.

(3) Glycolysis to form intermediate products.

(4) The last phase depends upon the presence or absence of oxygen (*a*) in the presence of oxygen—CO_2 and H_2O are the final products (*b*) in the absence of oxygen—alcohol and CO_2 are the final products.

It is thus generally accepted that **normal aerobic respiration involves an initial anaerobic phase.**

The fact that plants continue to evolve carbon dioxide in the absence of oxygen is easy to prove in the case of germinating seeds. In water previously boiled and cooled, soak a few seeds of *Cicer* or *Pisum* for a few hours. Peel off the seed coats of these seeds carefully without injuring the embryo. Fill a narrow test tube with mercury and invert it in a small dish of mercury by closing its mouth and clamp it to a stand. Pass three or four peeled seeds of *Cicer* or *Pisum* into the test tube containing mercury without admitting air, and by means of bent tube introduce a small quantity of boiled and cooled water into the test tube to keep the seeds moist. Observe the tube for one or two days and note that it is about half or one third full of gas. Pass into the test tube some more water and a piece of caustic potash. After sometime the mercury will rise to the top of the test tube due to the absorption of carbon dioxide by the caustic potash.

Comparison between Photosynthesis and Respiration

At this stage, a comparison between Photosynthesis and Respiration, two very fundamental physiological processes, is very necessary for a clear grasp of the essentials of these two very important phenomena.

Photosynthesis	Respiration
(1) Occurs only in **green** plants.	(1) Occurs in **all plants** and **animals.**
(2) A process confined only to the cells containing the **chlorophyll pigments.**	(2) **Every** living cell respires.
(3) **Light** is very necessary.	(3) **Light** or no **light** respiration goes on at **all** times from birth to death.
(4) Free energy is **light energy.**	(4) Free energy is **heat energy.**
(5) Food is **constructed** from simple compounds.	(5) Food is **broken down** into simpler compounds.

(6) **Increases** dry weight as a result of food production.	(6) **Decreases** dry weight as a result of breaking down food.
(7) Oxygen is **released** during the process.	(7) Oxygen is **consumed.**
(8) Water and carbon dioxide are very essential for the carrying on of this process.	(8) Water and carbon dioxide are released during the process.
(9) Energy is **stored** and made **potential.**	(9) Energy is **liberated** and made **kinetic** for all plant activities.

The part played by green plants is of the utmost importance in the economy of nature. The main work of a chlorophyll bearing plant is the continued transformation of the energy of sunlight into latent chemical energy. The chloroplast is an apparatus imbedded in the protoplasm for catching the sun's rays. In fact the plant is a machine whose work is to store up large quantities of latent energy by the absorption of sunlight. Thus we see that the **sources of energy is the sun.** As already pointed out, the formation of starch from simple inorganic substances is the only way by which organic matter is formed upon our planet :—

"Nature does not possess any other laboratory for the formation of organic matter except the leaf, or more strictly the chloroplast." The energy thus stored up is released by the process of respiration.

CHAPTER XXIV.

PHYSIOLOGY OF GROWTH.

Growth.

Plants manufacture large quantities of organic materials, portions of which are transformed into substances to be utilised in the formation of new cells and tissues. Both food-formation and growth take place in plants, but they may not go on at the same time and in the same place. As a matter of fact, we know that growth is actively going on in young parts of plants, whilst photosynthetic work and storage of material are the concern of the mature organs. Growth is localised at the free ends of leafy branches and roots. Once a plant begins its life, it goes on growing and living as long as favourable conditions continue. The same individual may continue to grow and exist for any length of time. But in nature we find some plants going through their whole development from the germination of the seed to the ripening of their seeds within a few months. After the production of seeds they cease to live. Many plants which we call **annuals** are of this kind. The life of the annual is connected with the seasons of the year.

We have also trees which live for many years, and these, however, cannot continue to live for ever, apparently on account of the increased difficulty of exchange of materials between the roots and the leaves. Further, it is not always possible to avoid external disturbances. If the exchange of materials between the roots and the leaves be facilitated, then growth may go on indefinitely. Consider the case of a tree such as the banyan which is capable of growing for a long time unceasingly and covering many acres of land by gradual extension if left undisturbed. The aerial roots penetrate the soil and facilitate not only the taking in of water and nutritive material and the exchange between the roots and the leaves, but also prop up very efficiently the branches. As instances of banyan trees that have been in existence for a very long time, we may mention two trees, one still growing in the neighbourhood of Madura Town and the other near the village Jakkeri in Hosur Taluk, both in South India. A magnificent specimen of this tree possessing hundreds of aerial roots and covering several acres of land is still growing in the Sibpur Botanic Gardens near Calcutta.

The giant trees of California, namely *Sequoia gigantea* seem to grow tall and live for many years. A magnificent photograph of this tree was published by the National Geographical Magazine of California some years back calling the tree, " The oldest Living Thing." Some details about this tree were also given in the letter-press as follows :—" A Towering giant among giants, the oldest living thing that connects the present with the dim past, majestic in its mien, its dignity and its world old experience. " The General Sherman-tree " is the patriarch of the Sequoia National Park of California. It was already 200 years old when Christ was born ....The " General Sherman " was discovered in 1879 by James Wolverton, a hunter and named by him in honour of General William T. Sherman. It towers 279.9 feet into the sky ; its base circumference is 102.8 ; its greatest diameter 36.5 and it has developed a diameter 17.7 feet at a point 100 feet above the ground."

Growth is essentially an increase in size caused by change of form resulting from a redistribution of material or by the addition of similar parts to the existing parts brought about by the use of fresh constructive material. Increase in size does not always mean increase in weight. A seedling though grown from a seed generally shows a loss of weight instead of gain.

Growth regions.—By observing an young leafy branch we can easily find out how growth progresses in it. Growth may take place in any of the dimensions, but the most obvious growth is in the length. Every growing young branch terminates in a leafy bud consisting of a short axis with closely packed immature leaves. Immediately below the terminal bud we find the young leaves separated from one another by internodes of different lengths. The distribution of growth in a young shoot can be studied, by marking the growing part with lines at equal intervals of a millimetre or one-sixteenth of an inch with waterproof ink, and observing the same marks after a day or two. By close observation in the manner stated above, we find that the greatest elongation takes place at some point below the tip. Above and below this portion elongation goes on diminishing, until it ceases above at tip and at a particular point at some distance below the elongating region.

The distribution of growth may be seen in the roots also. Compared with the stem, the region of most active growth is much shorter than in the stem. Select two or three seedlings of *Canavalia* or *Dolichos* with roots grown to about an inch long and mark the roots as indicated for the stem. Keep the seedlings on wet blotting

paper between two glass plates and rest the plates against one edge of a tray containing some water, so that they are in a somewhat slanting position. After a day or two examine the roots and note where the elongation has taken place. In the roots of *Cicer* and *Canavalia* the roots gave the following results when marks were made and observed :—

Canavalia seedling, marked into 8 divisions of one mm. each.

After 24 hours, no change in divisions 1, 2 & 4 : 3, 5 and 6 showed an elongation of 2 mm., 7 was 3 mm. and 8 was 8 mm.

Cicer seedling, marked inte ten divisions of one mm. each.

After 24 hours, 1 to 8 no change, 9 was 3 mm. and 10 was 7 mm.

After 48 hours, 1 to 8 no change, 9 and 10 were respectively 15 mm. (Fig. 241).

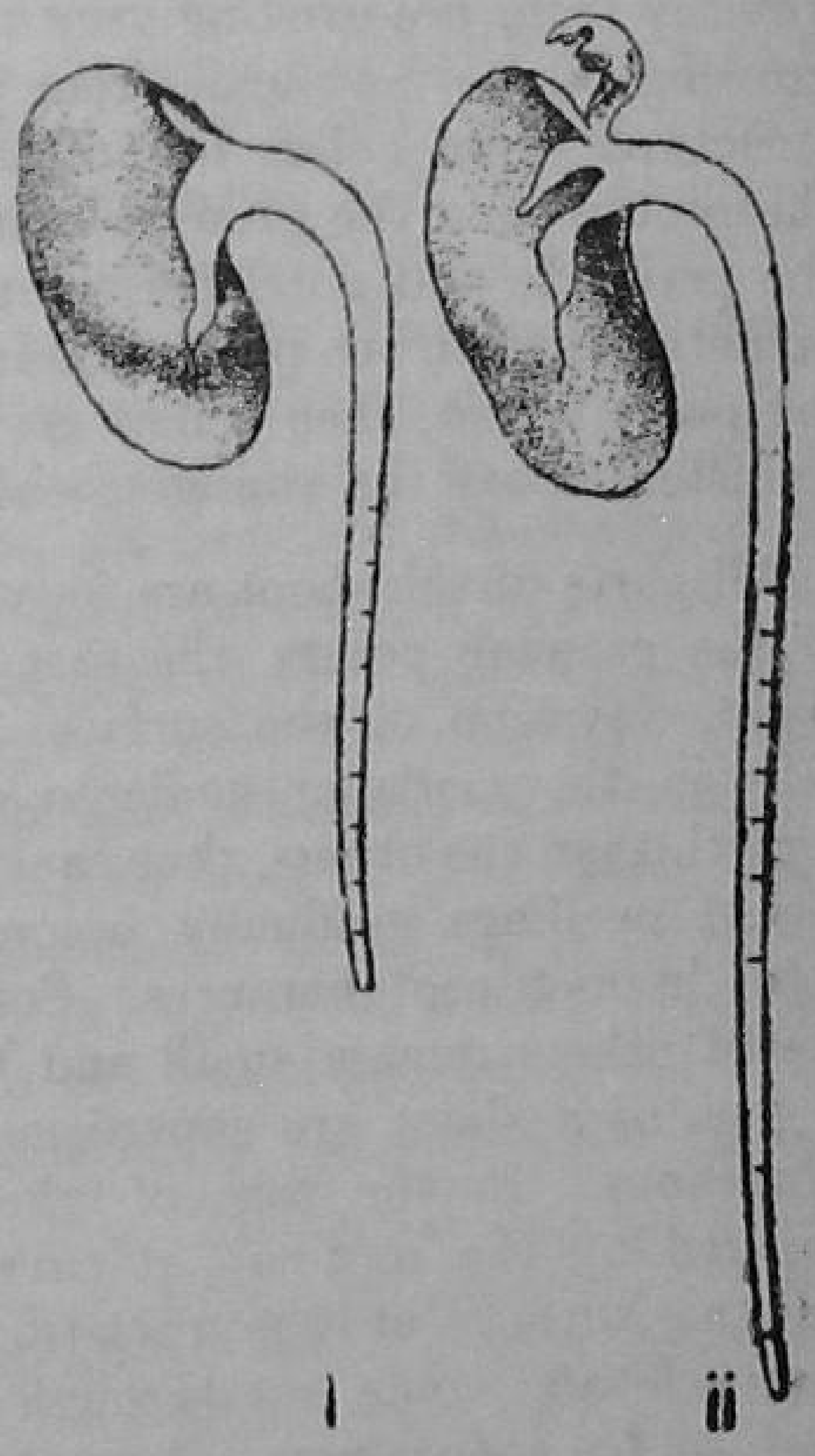


Fig. 241. Growth and elongation in roots.

In growing shoots the region of growth is longer than in the root. Even the growing portions are not elongating uniformly but are composed of zones passing gradually into one another, in which the rates of growth differ. In the shoots of some plants intercalary growth is a common feature. For example, in grass stems the portion of the internode just above the node keeps on growing long after the upper portion has become permanent and has ceased to elongate.

The elongation taking place in parts of plants depends upon the growth of the individual cells composing it. There are three phases in growth, namely, the formation of cells by cell division, increase in their dimensions and changes in the cell wall or differentiation. The extreme tip of the growing point consists of embryonic cells endowed with the power of constant cell division. Just a little below this the cells begin to grow in size especially in the longitudinal

direction parallel to the axis. Below this region changes in the cell walls take place. It should not be supposed that these three phases of growth are restricted to definite regions. One region passes into the other insensibly. Formation of new cells by cell division is the most prominent feature of the extreme tip and in the part behind, elongation is the chief feature, though differentiation may be going on here and there in certain cells.

Embryonic parts.—In the embryo plant, while within the seed, all the cells are in the embryonic stage. As germination progresses, only those cells at the extreme end of the plumule and the radicle remain in the formative phase, whilst the cells between these grow larger and longer. Therefore, in a higher plant the growing points of stems and roots alone consist of embryonic cells. The embryonic cells constitute the meristematic tissue. As a rule the growing points of the shoot system arise directly from pre-existing growing points. Occasionally, however, growing points may arise from permanent tissue as adventitious structures from callus or ordinary parenchyma. In the case of the root-system the growing points of the lateral roots arise from the pericycle and not from the growing point of the mother-root. Sometimes when the plumule is injured at its tip so that the growing point is lost, then a new growing point may develop from the meristem above the youngest leaf primordium.

All parts of the shoot are formed in the meristem at the surface of the growing points, the first indication of such parts being a slight elevation of the surface. At certain definite points some cells in the meristem undergo division and are more active in growth than the others, thus causing slight swellings on the surface. These swellings gradually become more prominent and develop into distinct protuberances. Some of them develop into leaves whilst others remain small and become axillary buds. Since the organs of a shoot are superficial in origin they are said to be **exogenous.** In the case of the root, the growing point being covered by the root-cap, it cannot give rise to any lateral root on the surface at the root-tip. Lateral roots arise from the pericycle and come out through the cortex, and hence these are said to be **endogenous.** Adventitious growing points developing into shoots often arise endogenously on roots and shoots.

Meristems form new tissues in plants. Primary meristems are present in growing points. Secondary meristems are formed for secondary increase in growth. There are three stages in growth: **formative** period, **elongation** period and **differentiation** period.

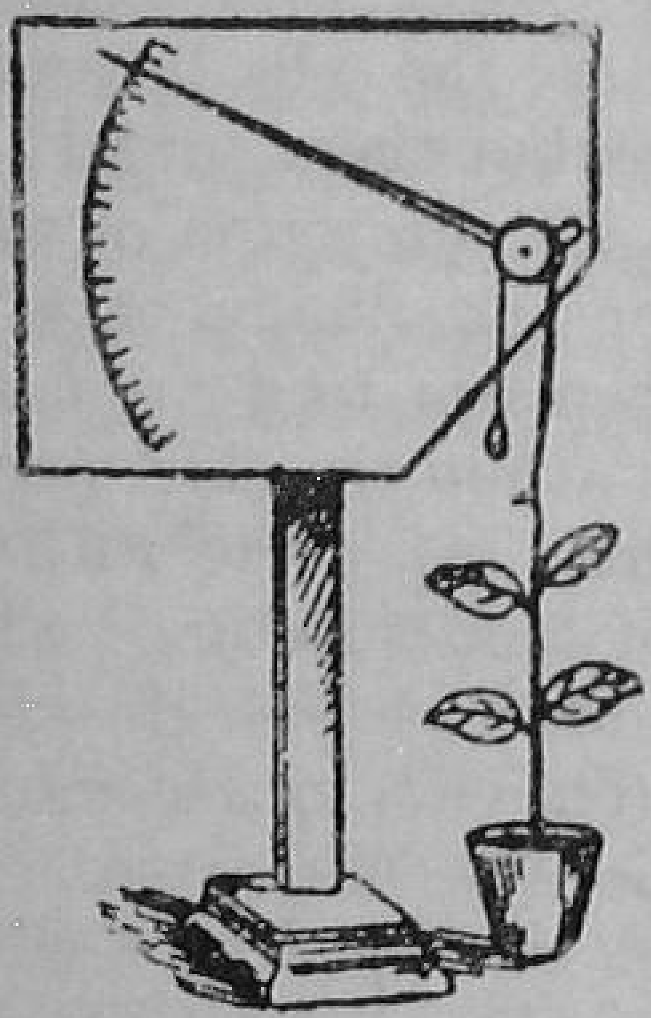
Elongation.—At the growing point whilst new cells are constantly produced, those already formed begin to change in size, shape and other characters. The most striking change in this phase of growth is the increase of size in a peculiar and economic way. The increase in size is usually a hundredfold or more, and it results chiefly from the absorption of water from without. The meristematic cells at the growing point usually contain considerable amounts of water and protoplasm also. More water is absorbed by these cells and they become turgid. The extra amount of water thus absorbed exerts pressure and stretches the cell wall. The protoplasm inside the cell which is ever active, adds some material to the cell wall so that it retains permanently the size it attains under pressure. This process of stretching of the cell wall and of addition of material leading to the further growth of the cell wall goes on until the cell attains its usual permanent form and maximum size.

No doubt the protoplasm also increases in quantity to a considerable extent, but much the greater part of the cell is occupied by water. As described above, water enters the cells because of the presence of osmotic substances, and makes them turgid. At first the minute vacuoles are enlarged and, as absorption of water proceeds these vacuoles become still larger and finally only one large vacuole may exist reducing the protoplasm to a primordial layer. It is indeed remarkable that plants attain the chief part of their enlargement, by means of water, thus dispensing with the necessity of using very large quantities of food substance which would be necessary, if the enlargement were to be brought about by increase in the amount of protoplasm. The cells in the embryonic stage have all the three dimensions more or less equal. Enlargement takes place in all directions, but not equally. Cells in some places may grow more rapidly in length than in their breadth, while others may increase more in the transverse direction. The process of elongation of any part is really the elongation of the cells constituting that part.

Measurement of growth.—The growth and elongation of parts in plants is generally so slow that it is imperceptible. But in some plants growth is so rapid as to be visible even to the naked eye. The stamens of grasses grow very rapidly in length. For example, it has been observed that the stamens of wheat grow in length at the rate of 1.8 mm. per minute. When the aerial shoots of *Musa paradisiaca* are cut across, we see within five minutes the young leaf stalk and the convolute leaf blade rising above the level to

about 1/5 to 1/4 inch, *i.e.*, an elongation of about 1.2 m.m. per minute. If the elongation of any part is carefully observed, it would be seen that the rate of growth in length is slow at first, then rapid until the maximum rate is reached, then slow and finally the part ceases to grow.

The growth in length of any part of a plant may be found out by means of an instrument called auxanometer. A very simple form of this instrument is shown in Fig. 242. The elongation is magnified many times and so it is easily observed. The long arm of the pulley should be at least twenty-five to thirty times the short arm. Then the rapidity of the growth would be magnified twenty-five to thirty times. By the use of an auxanometer we can measure only the total elongation. The manner of using this piece of apparatus may be inferred from the figure. Fig. 243 shows an instrument which automatically records growth. The instrument is called **Auxograph.**



Fig, 242, A simple Auxanomteer.

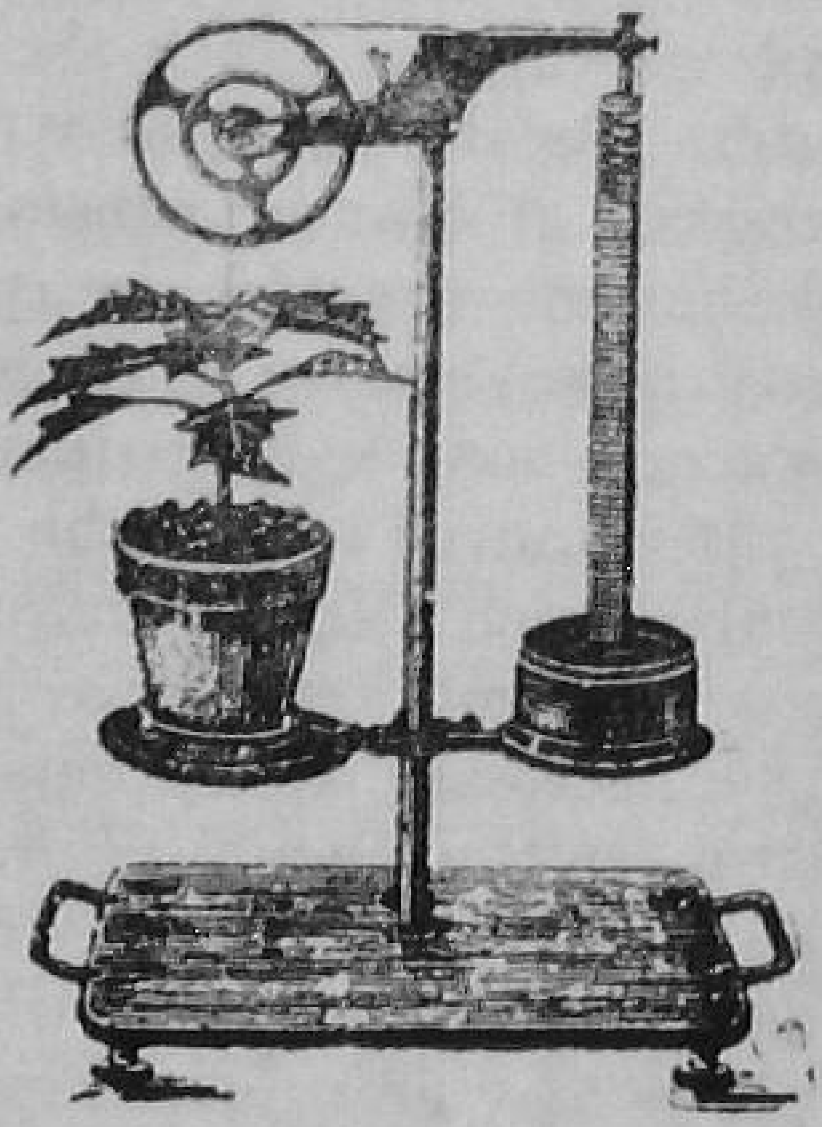


Fig. 243. Auxograph.

Conditions favouring growth.—(i) During the formation of new cells by cell division a large amount of constructive material is used up, and therefore, an adequate supply of plastic material is necessary. (ii) For this constructive work energy is obtained from respiration and so **oxygen** must be available, since in all higher plants respiration is possible only when this gas is present. In the neighbourhood of meristematic cells at the growing point, intercellular spaces exist which are connected with the spaces below and the lenticels, so that the outside air can freely find its way into these intercellular spaces. (iii) Embryonic cells must undergo

transformation before they can function. The increase in size of these cells and turgidity both being caused by water, it is evident that an adequate supply of **water** is essential. (iv) Temperature within a certain range is conducive to growth. Temperatures above the maximum and below the minimum retard the growth. (v) Light though essential for the well-being of the plant, inhibits growth, whilst darkness favours it. When dicotyledonous plants are grown in darkness, the stems become unusually elongated, white and soft. Leaves remain small, yellow and folded. Such plants are said to be **etiolated.** The influence of light seems to vary with the organs of plants. In some cases it causes the increase of growth, while in others it prevents it. Under light of moderate intensity leaves attain their maximum size. (vi) Growth responses involve a number of essential compounds which are essential for growth. If any of the essential compounds are missing there can be no growth. Such growth regulators can sometimes be artificially supplied to the plants.

Hormones and growth regulators.

The substances which regulate plant growth are known as **hormones.** Hormones are cellular secretions. They exert an influence on growth and development by controlling specific chemical reactions, possibly functioning as catalysts. The study of hormones, in the case of plants, has been dealt primarily with growth, wound healing, and regeneration. Haberlandt postulated specific wound-healing hormones in plants. In the case of plant movements brought about by curvatures (geotropic and phototropic), the cause of the unequal growth for producing a curvature is attributed to a hormone. The difference between vitamins and hormones is very subtle. Vitamins are regarded as **nutritive** and hormones purely **catalytic** ; vitamins **feed,** hormones **regulate.** In the case of both vitamins and hormones the quantity needed for action is very minute. The work during recent years shows that a variety of plant and animal material yield hormones :—fungus cultures, maize oil, yeast, human saliva, urine, etc. The name *auxin* has been given to the growth stimulating substance. Three auxins have been so far distinguished : auxin a ($C_{18}H_{32}O_5$), auxin *b*. ($C_{18}H_{30}O_4$), and heteroauxin ($C_{-10}H_9O_2N$). Corn oil is supposed to contain auxins *a* and *b*.

Vernalisation.

Vernalisation refers to a process of pre-treatment of seeds before sowing, as suggested by the Russian Botanist Lysenko. This process is of agricultural importance in that it accelarates

flowering. Normally, winter annuals are sown in the fall and they flower in the following spring. When sown in spring, they do not flower in the same summer. By vernalising the seeds, it was possible to sow these winter annuals in spring and make them flower the same season. It also converts late flowering forms into early flowering ones. This process is of great economic significance.

The treatment is simple. The seeds are soaked and when the radicle is just emerging, the moisture is so adjusted that further growth is arrested. The seeds are then subjected to the influence of factors, such as continuous light or continuous darkness, low or high temperature, which are capable of accelerating development. The main principles involved in such treatment are: (i) growth and development are two different processes in the plant, (ii) each requires a set of environmental factors for completion, (iii) development consists of at least five phases of which photo-phase and thermo-phase are the first two phases, (iv) the five phases proceed in strict sequence, (v) different phases require different environmental conditions for completion.

It may be briefly pointed out that vernalisation of different crops in India has not met with significant success. In Russia it is reported to be of great agricultural importance.

CHAPTER XXV

MOVEMENTS IN PLANTS

Irritability.—Every plant so long as it is alive, has to carry on metabolism, growth and development. If it is to perform all its functions properly, it must possess not only the power of placing all its organs in the position most appropriate for the due performance of their functions, but it should also have the power of responding in a suitable manner when changes occur. It is essential that the organs of a plant must occupy a position that is most advantageous for doing their functions, as otherwise living is impossible. So every plant must be able to shift its position either bodily, or to bring its organs into suitable positions. It is in virtue of the possession of this power that green unicellular plants and some of the algae move from a dark place to a lighted part. In the case of a higher plant, the foliage leaves must be so held as to enable all the leaves to obtain sufficient light, and the roots have to get into the soil and there branch in an adequate manner.

All movements in plants, resulting either in free locomotion of plants or in curvatures causing change of position in the organs of plants that are rooted to the soil, are due to the activity of protoplasm. We know that the most fundamental condition of life is the presence of living protoplasm. It is carrying on its activity by continual interaction with the factors amidst which it lives. Because of the presence of protoplasm in a living condition, the living plants possess the special characteristics of **irritability** and power of **regulation.** Protoplasm reacts to the external factors in a peculiar manner. This property of protoplasm is called **irritability**. The peculiarity of the behaviour of protoplasm when it is stimulated by an external factor lies in the fact that the reaction observed is not the direct effect of an external cause but a very indirect result. Further, according to the condition of protoplasm the same factor may produce different effects. For instance, the parts of a plant do not all respond to the stimulus of gravity in the same manner. Under this stimulus the main root of a plant goes vertically downward, while the main stem goes upward against gravitation.

Stimuli.—Higher plants show movements of organs whereas lower plants such as *Chlamydomonas* are themselves locomotory.

Gravity, light, moisture, chemical salts and shocks are some of the external stimuli to which the plants react. In the case of

lowly organised small green plants these external stimuli play a very special part in giving a definite direction to movements of locomotion. For example, when a glass jar containing living algae such as Volvox, Chlamydomonas, or Desmids is exposed to one-sided illumination, all the plants move towards the lighted side. Chloroplasts though imbedded in protoplasm possess the power of shifting themselves to such a position so that they can obtain the optimal amount of light. When the light is moderate the chloroplasts crowd together along the walls which are at right angles to the direction of the rays of light. They shift to the lateral walls and place themselves parallel to the cell wall as soon as the light becomes too intense so as to avoid the destructive action of light. In darkness or weak light they arrange themselves parallel to the lateral and inner walls.

Response to stimulus depends upon the condition of protoplasm. It must be in a condition to feel the stimulus and react. This is termed the *tone* or *tonus* of the protoplasm. Ancesthetics, temperature, lack of oxygen and stage of development bring about change in tone.

Kinds of movements.—Movements in plants are mainly of two kinds: (1) Movements which result due to the effect of external stimuli are termed **induced**, or **paratonic** movements, and (2) movements which result from internal stimuli termed **autonomic**, or **spontaneous** movements.

Paratonic movements.—Movements started by an external factor acting as a stimulus are called **induced** or **paratonic** movements. Under the stimulus of gravity, light and moisture, a plant causes its organs to be brought into positions in which their functions can be best performed. In other words, the significance of these paratonic movements lies in the attainment of favourable conditions of life. As already stated, the different organs of a plant react differently to the same stimulus. Some movements cause the organs to place themselves in particular directions with reference to the direction of the action of stimulus. Such movements as these are termed **tropisms. Taxis** indicates the movement of the whole organism directed by stimulus. If, under the same circumstances, plant organs assume definite position in relation to the plant rather than to the direction of the stimulus, movements causing such changes of position are called **nastic** movements.

The movements of orientation or tropisms, as they are called, are usually distinguished as **geotropism, photo-tropism** or **heliotropism, hydrotropism, chemotropism** and **thigmotropism** according to the stimuli that are responsible for the movement.

Geotropism.—Ordinarily the main branches of trees and shrubs grow vertically upwards, while their lateral branches assume other positions. The main root of a plant goes vertically downward in response to the stimulus of gravity. For the tap-root this is the position of rest or equilibrium, and the same stimulus has a different directive influence on the lateral roots. They take a horizontal course. Any disturbance of equilibrium in the root, or in the shoot causes the part disturbed to make a curvature which will enable the part to assume its positions of rest. That the varietal growth of the main root and main stem all over the world is due to gravity and that gravity acts differently on the stem and the root becomes clear if we bring a seedling to a horizontal position from its natural vertical position. When a seedling is treated thus, the two ends of the axis of the seedling show curvatures, whilst the middle portion of the axis remains horizontal. The tap-root curves vertically downwards a little behind the growing tip. This property of the root to move downward in response to the influence of gravity is called **positive geotropism.** As growth in length chiefly takes place just behind the root-tip, curvature can be formed only in this region. It should also be remembered that the root-tip alone is sensitive to the stimulus of gravity. When the actual growing tip of the root is cut off, no curvature is formed in the tap-root. However, as soon as a new growing point is formed the root responds. The stem also under similar circumstances responds by a curvature just behind the actual growing tip, but in a direction opposite to that taken by the root. Hence the shoot is said to be **negatively geotropic.** (Fig. 244)

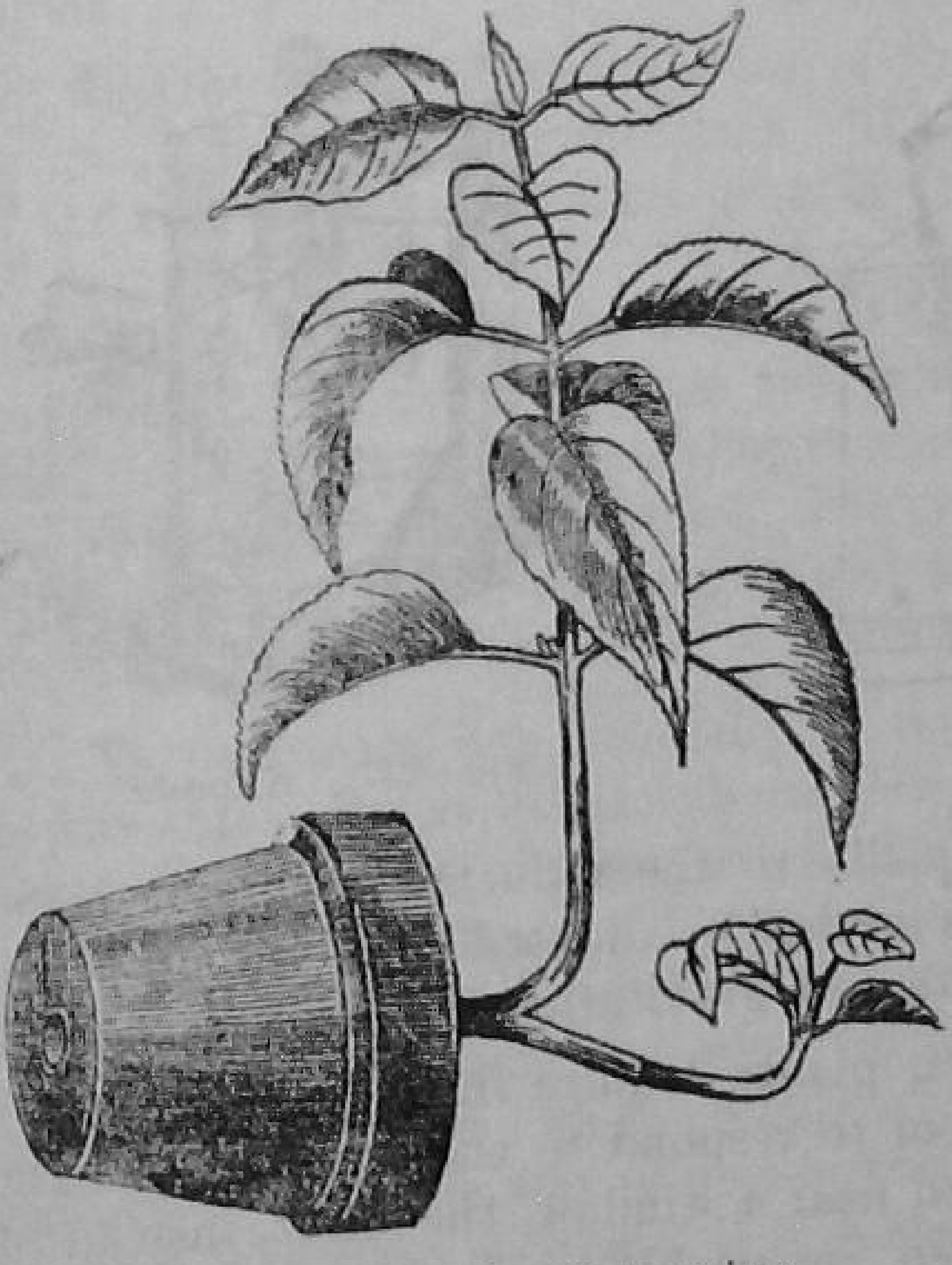
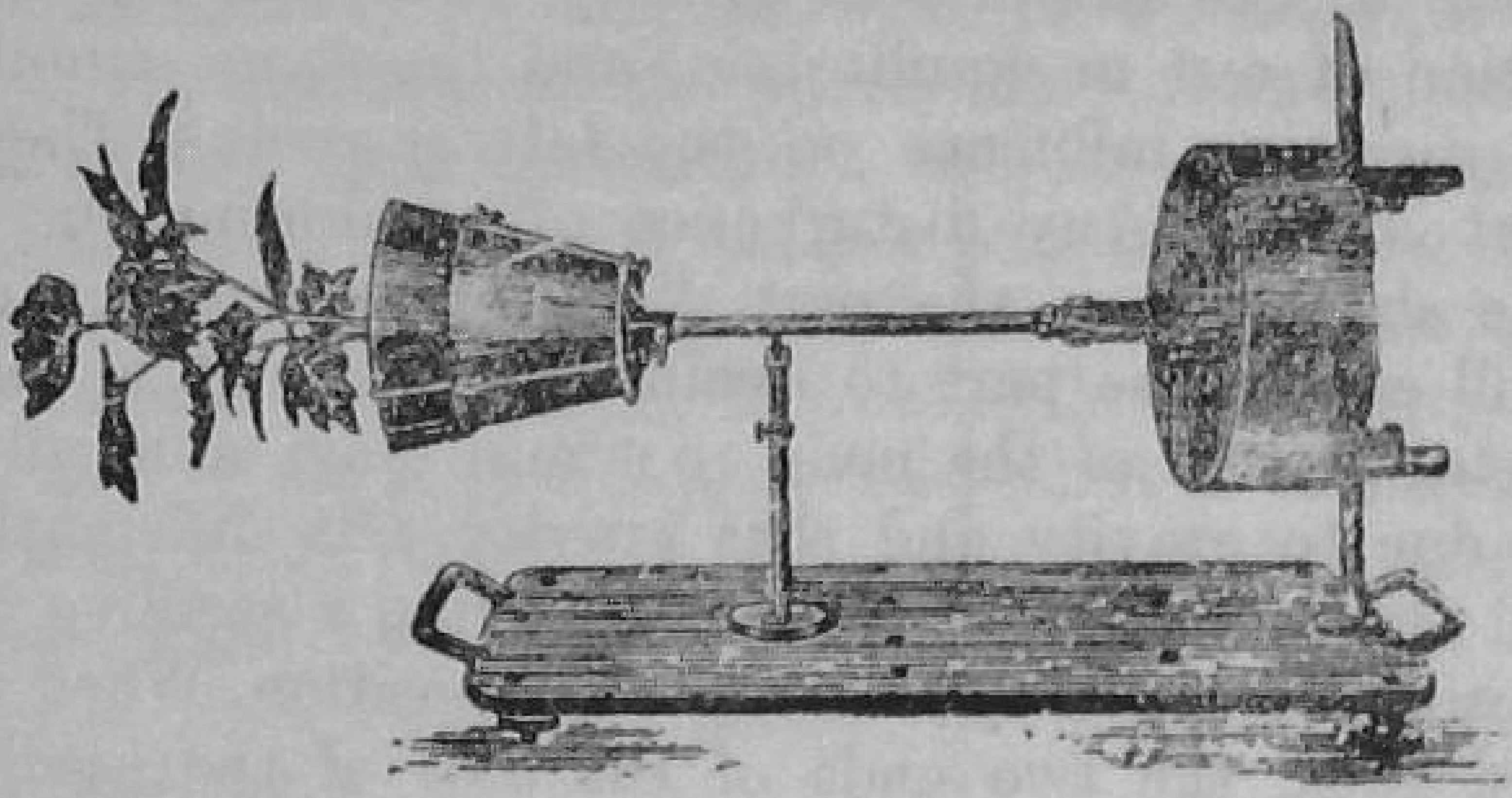


Fig. 244. Negative Geotropism.

By using the apparatus called the Klinostat we can demonstrate that the geotropic curvatures in roots and stems are really due

to the stimulus of gravity. (Figs. 245, 246, 247). This apparatus is a clock-work arrangement which causes an axis to rotate. After setting the Klinostat as shown in the figure, if we fix to the



Fig, 245. Klinostat.

rotating plate, seedlings in different directions, no curvatures are seen either in the root or the shoot. This is because the seedlings

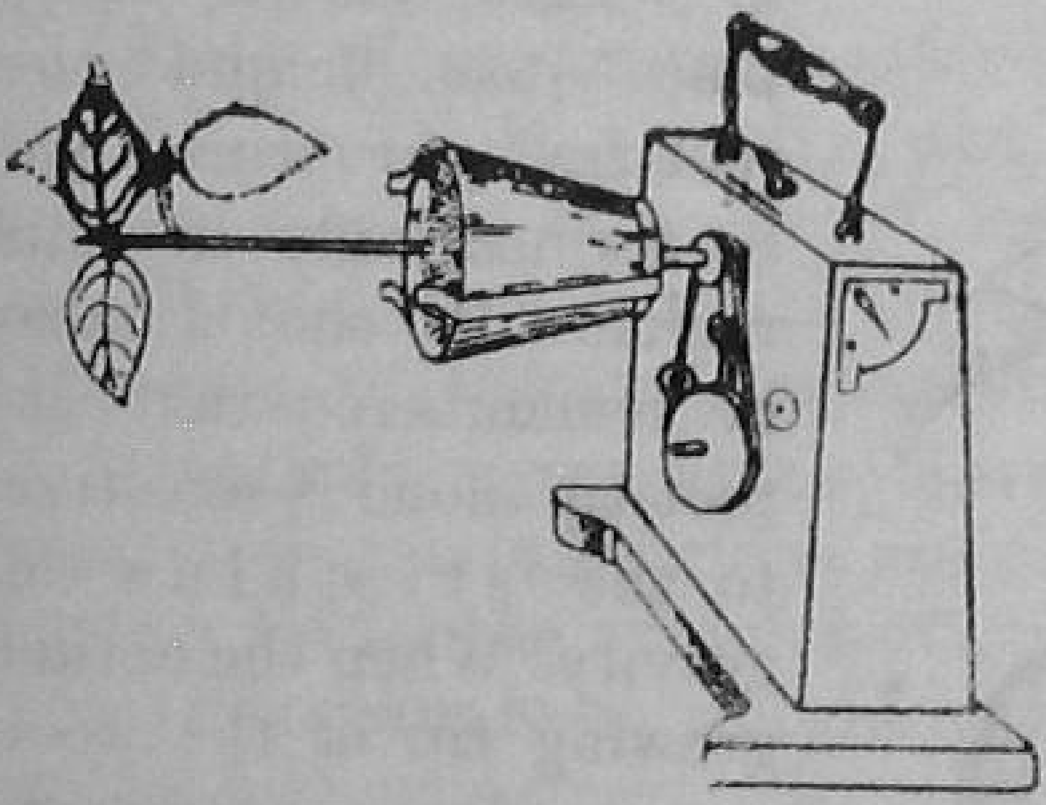


Fig. 246. Klinostat

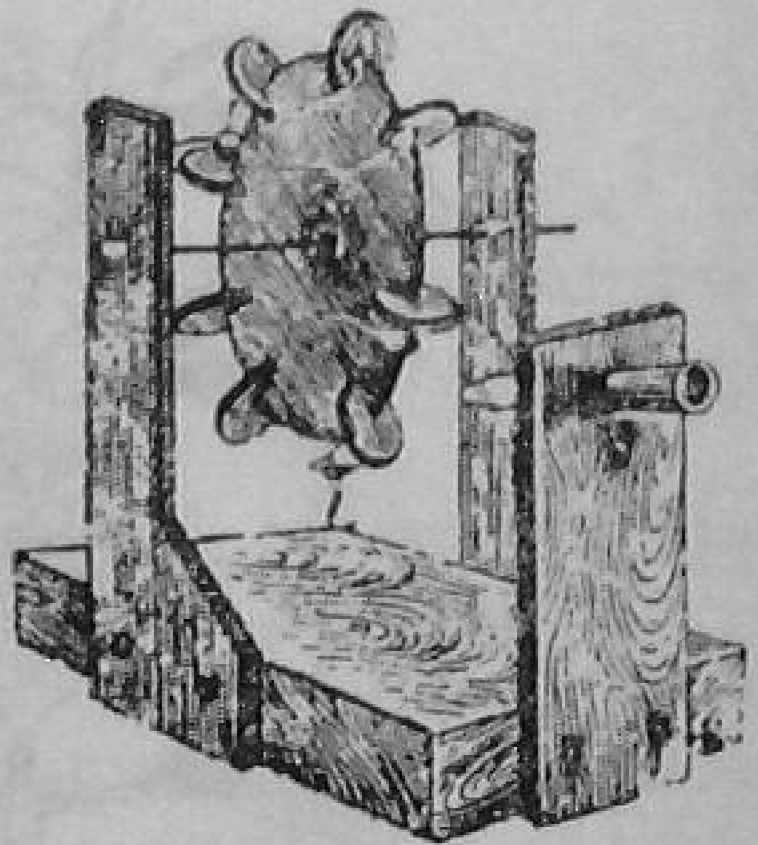


Fig. 247. Klinostat.

are exposed on all sides equally to the influence of gravity. So there is no curvature. This method is adopted as it is impossible otherwise to prevent the action of gravitation.

Phototropism.—As green plants require light for doing their work, we should expect them to respond to the stimulus of light also. When a plant is placed near a window, the shoot, instead of growing erect as in the open, invariably curves over towards it, because of the one-sided illumination. When a plant, fixed to the plate of a Klinostat rotating horizontally, is placed near a window, the stem does not curve towards the window, but grows erect. In this case all sides of the plant happen to be equally illuminated. A *Dolichos Lablab* seedling placed near a window

showed the curvature within twenty minutes. Plants growing in the open grow straight, for they are equally illuminated on all sides. In a shoot bending towards light the axis lies in the direction of the rays of light, whereas the leaves are either at right angles, or oblique. So the axis of the shoot is **positively heliotropic** or **phototropic** and the leaves are **transversely heliotropic** or **dia-phototropic.** This is another instance confirming the fact that the same stimulus acts differently on the different organs of a plant.

Tendrils, aerial roots and normal soil roots of plants are negatively phototropic. Seedlings of mustard when grown in water, as in water culture experiments, are highly sensitive to light. The shoot is positively phototropic and the root is negatively so.

In the case of all curvatures the actual bending occurs only in the region of maximum elongation, but the power of perception of the stimulus belongs to the younger parts above or below this region.

Hydrotropism.—The response of the root to the stimulus of moisture is called **hydrotropism.** The way in which the roots of the root-system of a plant grow in the soil is due to the stimuli of gravity and moisture. One may probably be led to wonder as to why the roots should be influenced in this manner by gravity and water. If we remember the functions that roots have to perform, it becomes obvious that it is necessary for the roots to be so affected by these two factors. The great need of the root-system is to explore the soil thoroughly and to come in contact with as much soil as possible, in order to do its work efficiently.

The tap-root has generally a tendency to grow vertically downwards. But it will not do so under all circusmtances. Sometimes, for the sake of moisture, it will move against the force of gravity. If in a large seedling-pan filled with sawdust or sand, we place in the centre a flower pot filled with water, and plant soaked seeds around it outside and allow them to sprout and develop into seedlings we shall find all the roots turned towards the pot, containing water. Another way of demonstrating this is to allow seedlings to grow in a sieve and hang it in a slanting position, when all the root tips will be bent towards the side where there is moisture. In the case of epiphytes the aerial roots sometimes grow straight up for the sake of attaching themselves to branches lying above them.

Chemotropism.—Movements of orientation stimulated by chemical substances are termed **Chemotropism.** When the

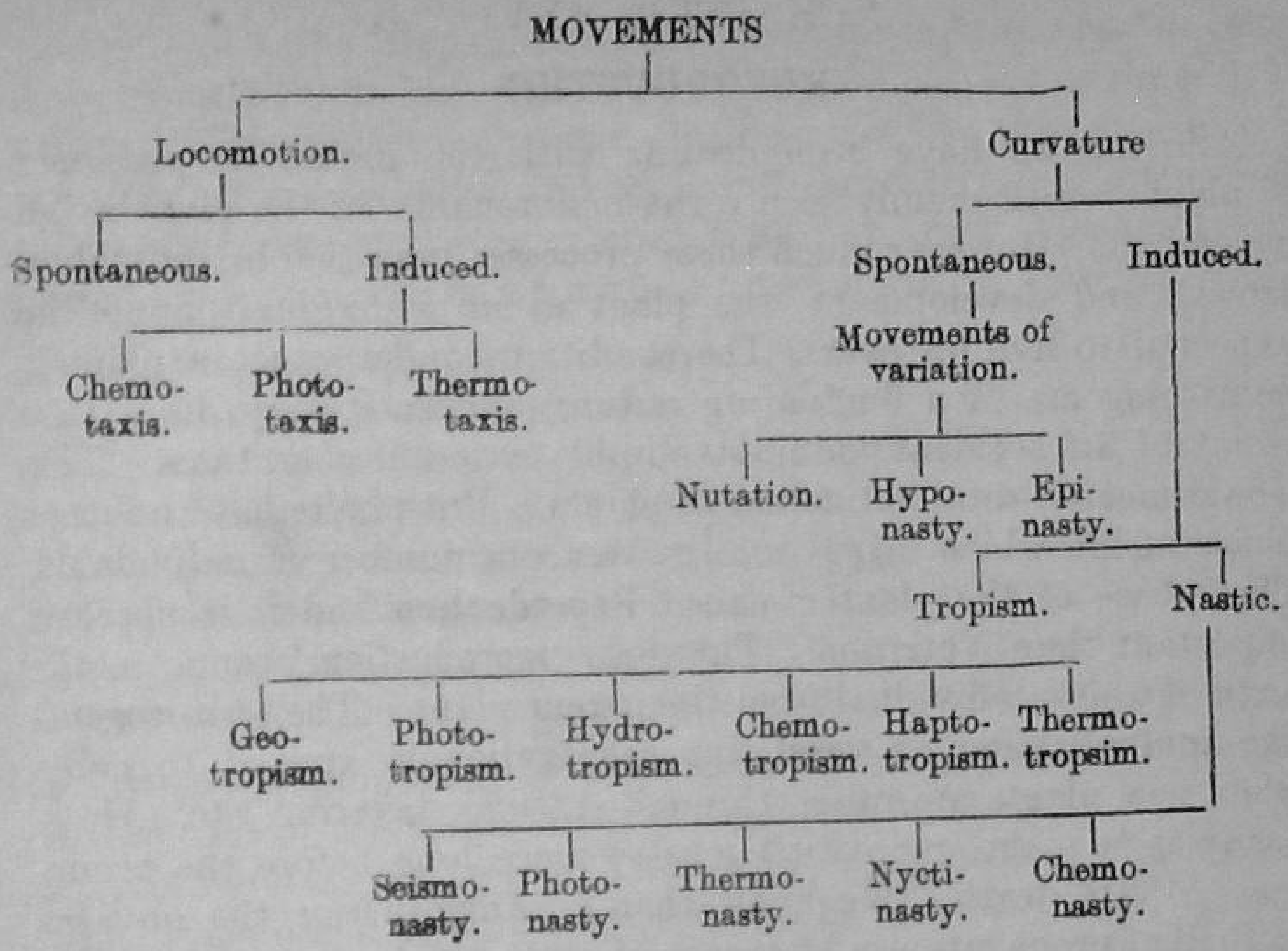
movement is towards the chemical substance it is termed **positive** chemotropism, and when it is away from the chemical substance it is termed **negative** chemotropism. Pollen tube growth is directed towards the ovule by chemotropism.

Thigmotropism or **Haptotropism** is applied to the sensitiveness to touch stimulus as shown by tendrils. Tendrils are sensitive to contact with solid bodies and when they fail to get a support, they wither and die. Parasites like *Cuscuta* are also sensitive to contact with the host plant and the development of haustoria is stimulated by such contact. Insectivorous plants perform haptotropic movements. In *Drosera,* when an insect lands at the centre of the lamina, the tentacles bend on to the centre and trap it.

Nyctinastic movement.—Floral parts and leaves take different positions by day and night, e.g., members of the families *Leguminosae, Oxalidaceae, Euphorbiaceae* and *Marantaceae.* The movements in these cases is not directional but diffuse. In tropism the movement is directed by stimulus.

(i) **Seismonastic movement.**—Some plants respond to shock. In haptotropism, the reacting organ comes into contact with a solid body but in seismonastic movement the shock may be carried even through the ground, e.g., *Mimosa pudica.*

(ii) **Autonomic movements.**—In plants under normal conditions and when all the general conditions of vital phenomena are present, movements occur without any special stimulus. For example, the movement of the stem and the root in a straight line and the unfolding of leaves in the leaf buds or flower buds caused by unequal growth are such movements, and these movements are called **autonomic** movements. If we carefully observe the tips of climbers they move about all round the points of the compass. This is called **circumnutation.** The movement caused in the unfolding of the leaves in a leaf bud is the result of unequal growth, the inner surface growing more rapidly than the outer. This is called **epinastic** movement. In Ferns the rolled condition of the circinate young leaf is due to the more rapid growth of cells of lower surface than the upper and this is **hyponastic** movement.


MOVEMENTS
Locomotion.
Curvature
Spontaneous.
Induced.
Chemo-taxis.
Photo-taxis.
Thermo-taxis.
Spontaneous.
Induced.
Movements of variation.
Nutation.
Hypo-nasty.
Epi-nasty.
Tropism.
Nastic.
Geo-tropism.
Photo-tropism.
Hydro-tropism.
Chemo-tropism.
Hapto-tropism.
Thermo-tropsim.
Seismo-nasty.
Photo-nasty.
Thermo-nasty.
Nycti-nasty.
Chemo-nasty.

CHAPTER XXVI

REPRODUCTION

So far we have been dealing with the metabolic processes of plants which mainly secure the maintenance of the plant as an individual. However much these processes may favour individual growth and development the plant as an individual cannot be expected to live for ever. The conditions under which a plant is flourishing are of a fluctuating nature, and so it may die as the result of an accident, or unfavourable external conditions. This would mean a total extinction of plants. But plants have another phase of life which brings into existence a number of individuals. This phase of the plant is called **Reproduction** and it is not less important than Nutrition. The term **'reproduction'** connotes the birth of a new individual from the parent plant. The term **vegetative multiplication** or **vegetative propagation** is applied to cases when new plants are raised through cuttings, layering, etc. Ordinarily in a plant, reproduction takes place long before the occurrence of its death. We know that in Angiosperms the obvious method of propagation is by means of seeds which separate from the parent plant and then give rise to new individuals. In the case of annuals the plant dries up after the production of a fairly large number of seeds, which are really so many inactive young plants in the embryonic stage. So, in Angiosperms, we clearly see a division of labour in the functions of nutrition and reproduction. The flower or a branch bearing sporophylls is the organ specially intended for the reproductive process and nutrition is the work of all the other parts of a plant.

In the case of flowering plants the obvious method of propagation is by means of seeds that are produced by the sexual process. In plants the reproductive bodies are usually small in size compared with the vegetative organs. Consequently a plant is able to produce numerous reproductive bodies or seeds, thus fulfilling the object of reproduction. As already remarked elsewhere, an apparently prodigal production of seeds containing germs is a necessity. Plants have two distinct modes of reproduction. They are the **sexual** or **digenetic** reproduction and the **vegetative** or **monogenetic** reproduction.

Sexual.—The essential feature of sexual reproduction is the union of the sperm cell with the egg-cell. Neither of these is capable of producing an individual directly. It is only after the fusion of the two sex cells that the new individual can be formed. Before fusion these sex-cells contain only half the number of chromosomes found in the somatic cells. So the cell resulting from the fusion

contains as many chromosomes as there are in the somatic cells. The sex-cells before fusion are haploid and the oospore or the fertilised egg-cell is diploid. Further, this fusion is also the cause of the mingling of the paternal and maternal characters. Since the sex-cells giving rise to the germ arise from two distinct sources, the sexual mode of reproduction is also termed **digenetic** reproduction.

In the lower plants the oospore surrounds itself with a cell wall and it germinates after a period of rest. But in the higher plants the oospore begins to divide immediately. By frequent cell division and growth, a multicellular embryo is formed. Forthwith this embryo continues its further growth and development in **Bryophyta** and **Pteridophyta.** But in Angiosperms the growth of the embryo is stopped generally as soon as the seed is formed and is commenced after a period of rest, when the seed germinates.

Reproduction may be considered to be a phase of growth. In the case of the simplest lowly organised plants such as *Pleurococcus*, diatoms, etc., reproduction is merely a process of cell division. The single cell undergoes division. The two cells formed by cell division separate and become two distinct individuals. In more complex plants also vegetative growth often passes gradually into reproduction. For example, in the filamentous algae such as *Oscillatoria*, *Spirogyra* and others, the filaments break up into bits and these bits grow and become independent plants. Even in some Angiospermous aquatic plants branches get separated and each of them grows and becomes an independent plant. In all these plants it is the detachment from the parent that defines the individual. Besides these multicellular bodies, in many cryptogamic plants spores are formed, which bring about propagation. The spores are unicellular bodies.

Vegetative propagation.—In nature vegetative propagation is wide-spread. This process is merely the separation of a part of the plant which becomes established as a separate individual quite independent of the parent physiologically. The separation of the part may be caused in various ways. It may be by the death of the parent, or due to the rupture or death of tissues. Plants such as *Lippia nodiflora* and *Centella asiatica* flourish everywhere. In all these plants branches creep along the surface of the ground producing roots at the nodes. These plants may go on increasing by growth and establishing new colonies in any number and occupy within a short time considerable areas, because of the capacity of becoming independent plants possessed by the creeping branches, when they get severed from the older portions either by decay or accident.

By the independent establishment of axillary buds and when bits of ordinary branches are detached from the parent plant, new plants arise. In many aquatic plants such as *Ceratophyllum demersum, Utricularia flexuosa* and *Elodea canadensis*, branches become separated, and these become independent plants. In some of these plants the terminal buds detach themselves and sink to the bottom of the pond. Later on these grow and become independent plants. Plants such as *Convolvulus arvensis, Clerodendron phlomoides* and *Aristolochia bracteata* get propagated by very small bits of their stems. These plants have an extensive system of underground stems that are very brittle. Even small bits of these branches are capable of growing into separate plants, either by the development of the buds already in existence or by the formation of adventitious buds. On account of this special feature these plants are the most troublesome and persistent weeds.

Adventitious buds develop at the margin of the leaves of *Bryophyllum calycinum* and these buds grow into separate plants. In *Scilla indica*, when the leaf apex comes in contact with the moist soil, an adventitious bud is developed on it, and this establishes itself as an independent plant. A *Begonia* leaf is induced to form adventitious buds by making incisions in them, and these buds are used for propagation. Very often the callus formed at the cut ends of roots and shoots develop adventitious buds. This affords another means of propagation.

There are many plants with subterranean stems in which the reserve food material is stored in abundance, such as rhizomes,

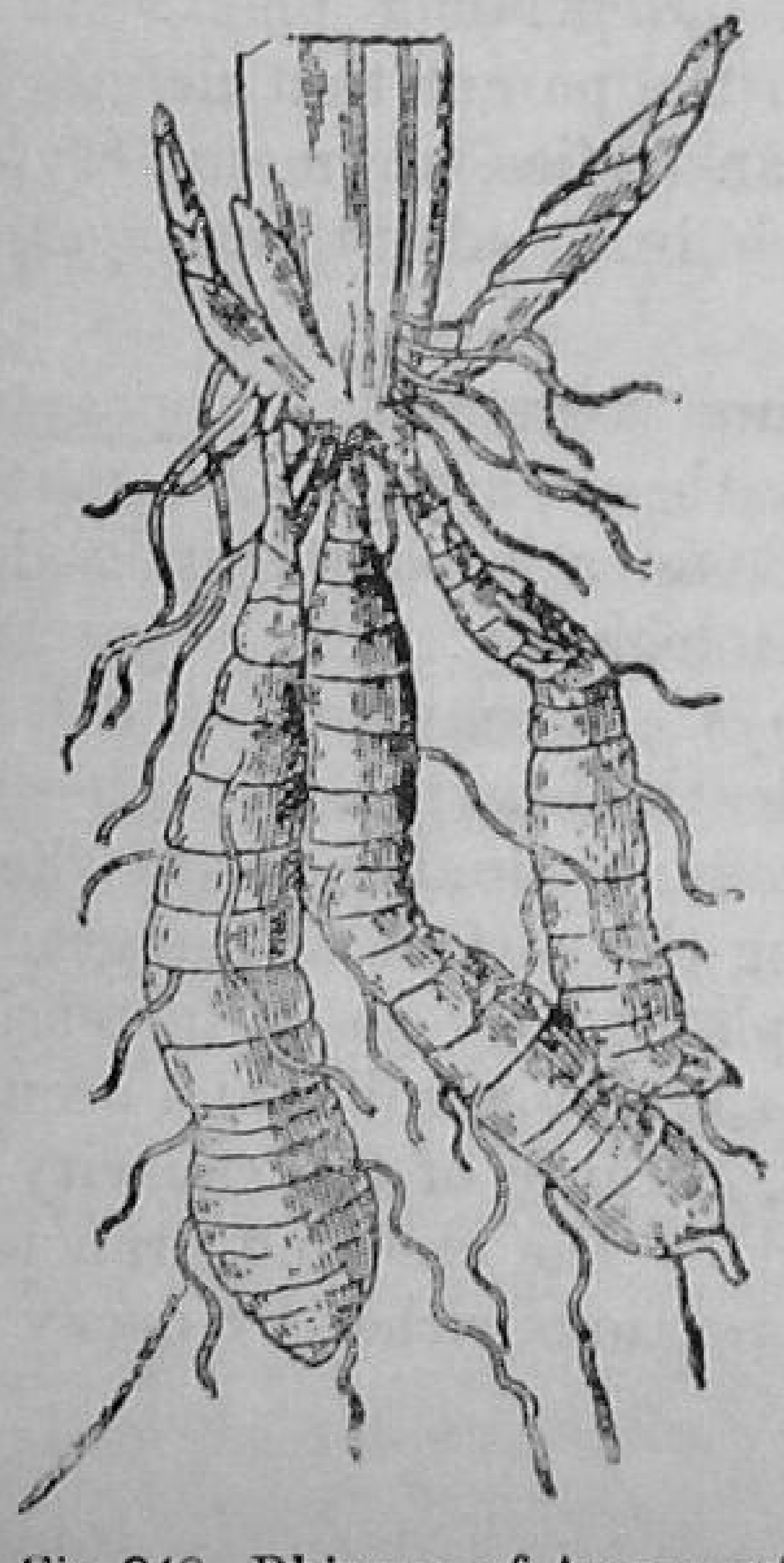


Fig 248. Rhizome of Arrowroot

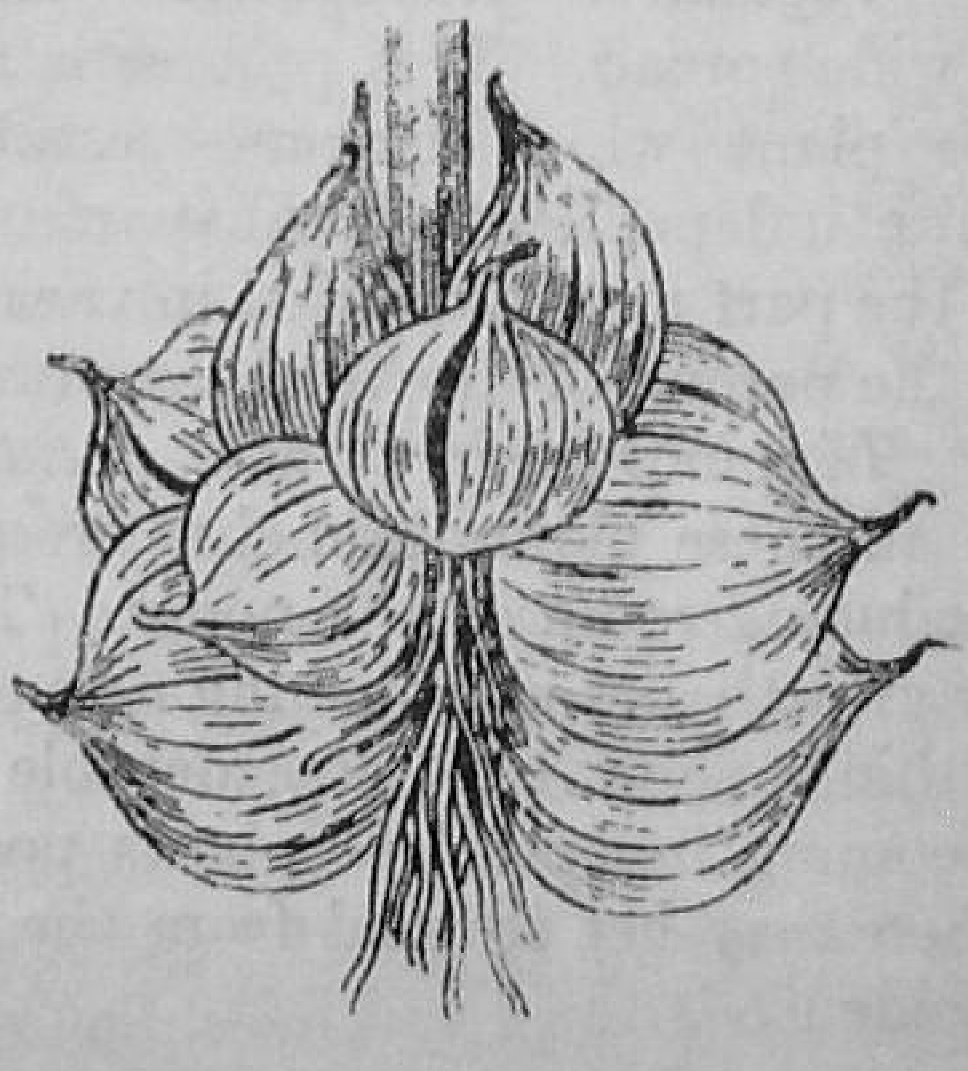


Fig. 249. Onion bulbs.

corms and bulbs that are specially adapted for the propagation of their kind.

The aerial branches developed from stolons or rhizomes remain connected with the underground stem, until they become fully established. Afterwards they are capable of separate existence as individuals. Soon after separation they are able to carry on the work of nutrition because they possess roots and green leaves.

Fig. 250. A *Chlorophytum* plant bearing young plants developed from bulbils formed in the inflorescence. 1. rachis of the inflorescence; 2. young plants on the rachis; 3. root of the plant.

Now coming to the very much modified stems such as thick rhizomes, tubers, corms and bulbs, these are certainly much better fitted for vegetative propagation than stolons or runners, as the abundant storage of reserve food is a positive advantage to start their growth. In these cases the separation from the main plant may take place long before the appearance of the daughter plants.

In the potato plant tubers are formed at the ends of branches, after they burrow themselves into the soil. Sometimes even the seedling of a potato raised from a seed may form tubers from the axillary buds of the cotyledons. These tubers are capable of growing into separate plants when detached from the parent plant. Some plants form small aerial tubers in the axils of aerial branches. In many cultivated species of *Dioscorea* aerial tubers develop from the axils and these fall off and grow into separate plants. In some species of *Agave* bulbils appear in the inflorescence and they drop down and develop into separate plants. We often find in some species of *Chlorophytum* grown in gardens bulbils in the inflorescences and they develop aerial roots and leaves in abundance before they get detached. (Fig. 251).

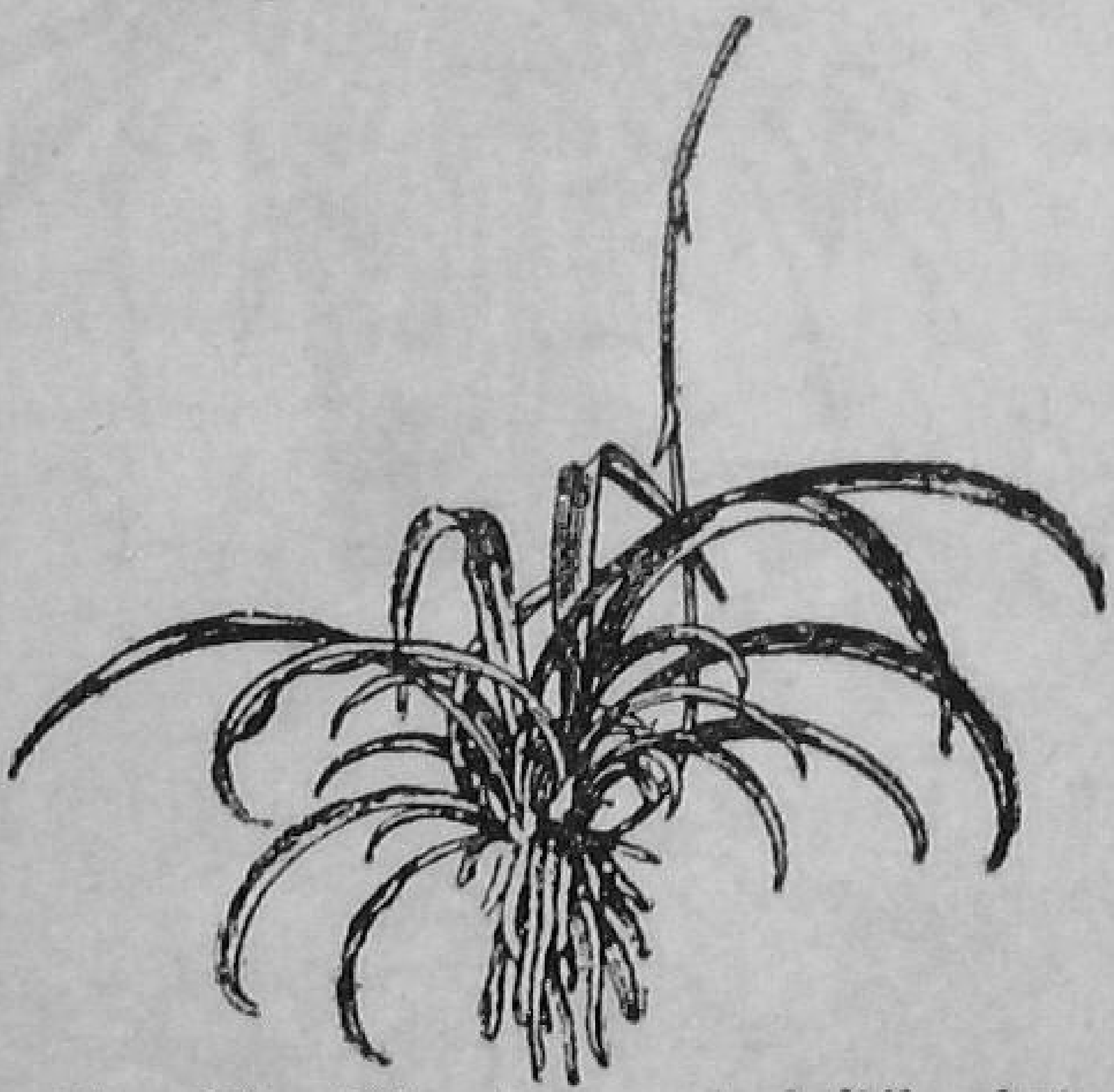


Fig. 251. *Chlorophytum.* A bulbil of the inflorescence grown into a plant.

In a corm the reserve material is allowed to accumulate in the main stem and all the buds remain on the surface of the corm. All the buds found in a corm are capable of developing into new corms in their turn, although it is the terminal bud which usually grows and becomes the new corm. Generally corms of two or three seasons remain together. In bulbs we find many daughter bulbs, which are really axillary buds, and by these the plant is multiplied.

Plants under cultivation are very largely propagated by the vegetative method. Raising of plants by grafting, layering and by means of cuttings is undoubtedly vegetative propagation.

Often we see plants that are able to propagate themselves by both digenetic and monogenetic modes of reproduction. Sometimes they adopt the former method and at other times the latter mode, according to circumstances. From this it is clear that there should be certain factors which determine the kind of reproduction to be adopted by the plant, when it is capable of both sexual and asexual reproduction. From observation in nature it is evident that sexual reproduction is not essential to the maintenance of the species and that flowers are formed only under definite conditions. When a plant gets plenty of water and nutrient salts and is able to carry on the work of photosynthesis, it continues to grow purely vegetatively. If the absorption of water and salts is limited, even with good light for photosynthesis, the plant produces flowers. Plants with a moderate absorption of water and nutrient salts produce flowers when the illumination is strong, and in weak light vegetative growth alone takes place.

Plants can propagate themselves continuously by vegetative means. Cases are known especially among cultivated flowering plants where propagation is effected continuously only by this method. For instance, the Pineapple and *Musa paradisiaca*, which are seedless and the sugarcane, which produces seeds under certain conditions are always propagated only vegetatively. The Jerusalem Artichoke (*Helianthus tuberosus*) has been known to be propagated only from tubers for over a century or two.

The progenies.—The nature of the offspring of a plant will vary with the kind of reproduction. If the offspring has resulted from vegetative reproduction, they will maintain the characteristics of their parent plant. The vegetative method of propagation will, therefore, enable any one to propagate a variety or form without any change in its character, and make it occupy the land quickly. But it must be remembered that plants produced by vegetative propagation are less able to withstand changes in their environments than those derived from seeds. With plants produced by the sexual method, it is far otherwise. In this case the fusion of cells from two different individuals, which is the chief feature of the process, changes the character of the offspring in a profound manner. Generally the offspring differ from their parents in some respects at least. Some of the offspring may be like one parent, some like the other and some others may differ from both. No doubt the young plants may resemble the parents

in a general way but on close inspection differences also will become apparent. This tendency is an advantage, if new varieties are required and in nature it leads to the formation of new plants. To make this point clear we may take the case of the propagation of the mango. If one wishes to have mango plants of a particular variety in large numbers, he should adopt the method of grafting, *i.e.*, vegetative propagation, but if the object is to obtain different varieties, he must have recourse to seeds that result from sexual reproduction.

Factors influencing reproduction.—The formation of reproductive bodies is a **phase of development** in plants. Annuals complete their life-cycle in one season, perennials produce flowers and fruits over a number of seasons and in the multiennials like *Agave americana* the vegetative development progresses over a number of years before the plant flowers and the plant dies thereafter.

Once it was considered that vegetative growth and reproductive phase are antagonistic to each other. Klebs showed that certain external factors govern the same while some internal factors also play an important role.

Water supply, presence of certain salts, humidity and light are some of the external factors influencing reproduction.

Vernalisation of seeds has been already discussed. It is an agricultural practice developed in Russia, for accelerating development of plants.

Duration of light has considerable influence on growth and reproduction and this is termed **photoperiodism.** Plants which flower under long-day conditions are termed **long-day plants** and those which flower under short-day conditions are termed **short-day plants.**

Many botanists explain the physiological phenomena underlying growth and reproduction on the basis of **Carbohydrate-Nitrogen (C/N) ratio.**

SECTION IV

CRYPTOGAMS

Thallophyta, simple undifferentiated plants. Never developing roots, stems, or leaves.	2. Fungi (Plants without chlorophyll).	Yeasts, Molds, Mildews, Smuts, Rusts, Mushrooms, Puffballs, etc.
	3. Chlorophyllous forms.	Algae, including sea weeds, pond scums, etc., *e.g*, spirogyra, ulothrix, vawcheria, chara, etc.
Higher Cryptogams ..	Bryophyta-vascular tissues absent.	Hepaticeae (Liverworts), *eg..* Riccia and Marchantia. Musci-Mosses, *e.g*, Funaria, Poganatum.
	Pteridophyta-Vascular tissues present.	Filicales or True ferns, *e.g*, Adiantum. Equisetales, *e.g*, Equisetum. Lycopodiales, *e.g*, Lycopdium, Selaginella.

BACTERIA

Introduction.—These are tiny living bodies that were discovered through the microscope nearly three hundred years ago. A linen draper in Holland, Leeuwenhoek, looking through his microscope found that clear water contained thousands of tiny specks which seemed to be alive for they could " swim backwards and forwards and twist themselves in an extremely lively fashion." To-day we have a great deal of information about these specks, which were given first the name " microbe " which comes from the " French " and it means " little bits of life ". Sometimes the term germ is used as a synonym, but it has so many other meanings that in use is apt to cause confusion.

Bacteria are plants and not animals.—Bacteria are regarded as plants though the earlier observers thought they were animals because they were found to be motile. One can easily distinguish a higher plant like the Cotton or the Rose from a higher animal like the dog or a rabbit, since there are many points of contrast plainly to be seen. With the microscopic organisms much greater difficulty is often experienced. Because there are among the bacteria forms which resemble simple protozoa. Bacteria are considered as plants because (1) they possess a firm wall like other plants. (2) The bacterial cell walls do resemble those of plants in their chemical composition and the resemblance is to those of fungi and to certain of the algae. (3) The relationship of certain groups of bacteria to the blue green algae (schizophyceae) is particularly close. (4) In many cases it would be reasonable to regard the bacteria as algae which had lost their chlorophyll. Some bacteria possess pigments which function somewhat as does chlorophyll in the green plants in enabling the cells to utilize the energy of sunlight in building up foods from carbon-dioxide. Such forms indicate close

affinities to the algae. (5) Certain groups of the bacteria show almost every intergradation with certain of the fungi, both in shape and branching of cells and in reproduction. (6) Many of them are motile, swimming about actively in water by means of whiplike organs of locomotion called flagella. Motility is but a characteristic of animals only. Many of the algae, some of the fungi and certain of the reproductive cells (sperms) of other plants, such as mosses, ferns, cycads, show motility. For all these valid reasons, bacteria are to be regarded as plants and not animals.

The importance of Bacteria.—The study of bacteria is important to us in more than one way. It is of major importance in determining the maintenance of good health in man and animals and sometimes in plants too. In modern times, there is an increasing tendency for people to live in crowded cities. Due to insanitary conditions under which they live crowded, there are chances for the out-break of epidemics caused by bacteria. A thorough knowledge of bacteria is essential to prevent their spread and also to protect ourselves from such bacterial diseases.

We are surrounded by millions and millions of bacteria which are found in the air we breathe and in the water we drink, in the food we eat, in the soil we inhabit and in many other situations with which we have daily contact. Therefore a knowledge of bacteriology is necessary for us to protect ourselves from some of these bacteria which are extremely harmful, i.e., the pathogenic bacteria. This knowledge plays a tremendous part in preventive medicine.

Many types of bacteria are responsible for the damage caused to our food materials when stored. For example, milk when stored in open vessels becomes soon fermented ; vegetables, when similarly stored, soon decay. Bacteriologists have devised special methods of packing and storing under which conditions the food materials are kept free from such bacteria. These food materials are then in a fit condition for transport to distant places without damage.

Several industries are concerned with the chemical changes produced by the bacteria. These are especially important in fermentation and the special branch of science dealing with the utilisation of bacteria in fermentation is termed **zymology or zymotechnique.**

Bacteria are also important in Agriculture. Of the many bacteria present in soil, some are beneficial and some are harmful. Thus, there is a group of bacteria which convert the free nitrogen of the air into nitrates in which form only, the plants can utilize the nitrogen. There is another group which, in association with leguminous plants, fixes atmospheric nitrogen in the root

nodules thus benefiting the leguminous crops, as well as the other crops that follow in rotation in that *field*. The agricultural practices are designed to encourage the useful bacteria and hinder the harmful ones.

Thus, the study of bacteria is important in our every day life, as well as, in industries, trades and prosperity in general of a country.

Brief history of the Science.—The science is of comparatively recent origin. It may be roughly said to be 50 years old. It is only with the development and sufficient perfection of the compound microscope that a study of these organisms was made possible. Dolland, in 1844, first used the principle of immersion with the lens, which later evolved into the oil immersion objective of the modern microscope so universally used in all biological laboratories. The sub-stage condenser of Abbe, developed in 1870 enabled us to perfect objective with higher powers of magnification. Each advance thus was marked by a better knowledge of the morphology of bacteria. It was only about the middle of the 19th century, certain scientists suggested that bacteria probably were to be regarded as plants and not as animals, as had been suffered up to that time. This enabled the German botanist Cohn (1872—1876) to work out the first reasonably complete classification of bacteria as a distinct group of plants.

A very important factor which considerably influenced the development of bacteriology was the controversy over the spontaneous generation of living things, that is the development of life *de novo*. It was thought that frogs and worms originated spontaneously from the bund of ponds and that decaying or dead tissues gave rise to bacteria. But Spallanzani (1777) was able to show that bacteria usually did not develop in food material which had been boiled for a time and then hermetically sealed away from the air. Schulze (1836) and Schwann (1837) confirmed the findings of Spallanzani by their more elaborate experiments. Schroder and Dusch in 1854 showed that filtration of air through sterile cotton filters, quite completely removed its power of inducing the development of micro-organisms in boiled liquids kept in flasks. Pasteur (1860) and Tyndall proved that micro-organisms were in air, and that organisms did not have a spontaneous generation and each organism had its birth from a pre-existing organism of the same kind. This knowledge is of great importance to us in that we now know no cholera or tubercular germ can arise without a pre-existing cholera or tubercular germ. Pasteur was responsible for making people believe by means of his experiments

that the alcoholic fermentation of sugar commonly due to the presence of yeasts, the souring of milk and the transformation of wine into vinegar are due to the activity of bacteria.

That bacteria could cause disease was first demonstrated by Davaine (1863) who found that the blood of animals attacked by the disease anthrax, contained rod-shaped micro-organisms, and that the disease was transmitted by transfer of such blood to a healthy individual. Koch went a step further and prepared cultures of these organisms. The next step was the advance made in staining techniques. To day we know that there are diseases which are infectious caused by germs and others non-infectious which are not caused by germs.

The development of the germ theory of diseases, as it is called, has quite completely revolutionised much of the practice of modern medicine. It has considerably influenced the direction and magnitude of growth of modern sanitary science and of preventive medicine. The Guindy Institute at Madras, Pasteur Institute, Coonoor, Haffkine Institute, Bombay, are all busy with bacteriological work in connection with preparation of preventive medicine.

Morphology of Bacteria.

Shape of Bacterial Cells.—Bacterial cells are usually of three shapes; namely, spheres, straight rods or bent rods; sometimes rods when long, are filamentous. Other shapes are also encountered (*see* Fig. 252).

A spherical organism is known as a coccus. A rod-shaped organism is termed a bacillus. The rod may be long or short, it may have rounded ends; or they may be truncate or even concave. A single cell which may show several turns of the spiral organism is called a spirillum. It may be slender or broad, short or long. A single cell may show several turns of the spiral, or may be so short as to appear as a slightly bent rod.

Filamentous bacteria are also called the tricho-bacteria.

It is to be noted that the cells of a particular kind of bacterium are not always of the same shape. An organism may be a bacillus under one set of environmental conditions and a coccus under another.

The grouping and arrangement of Bacterial Cells.—Bacterial cells are frequently surrounded by a thin and very rarely a thick layer of gelatinous material which enables the cells to cling together. The shape of the group of cells thus formed and the cell

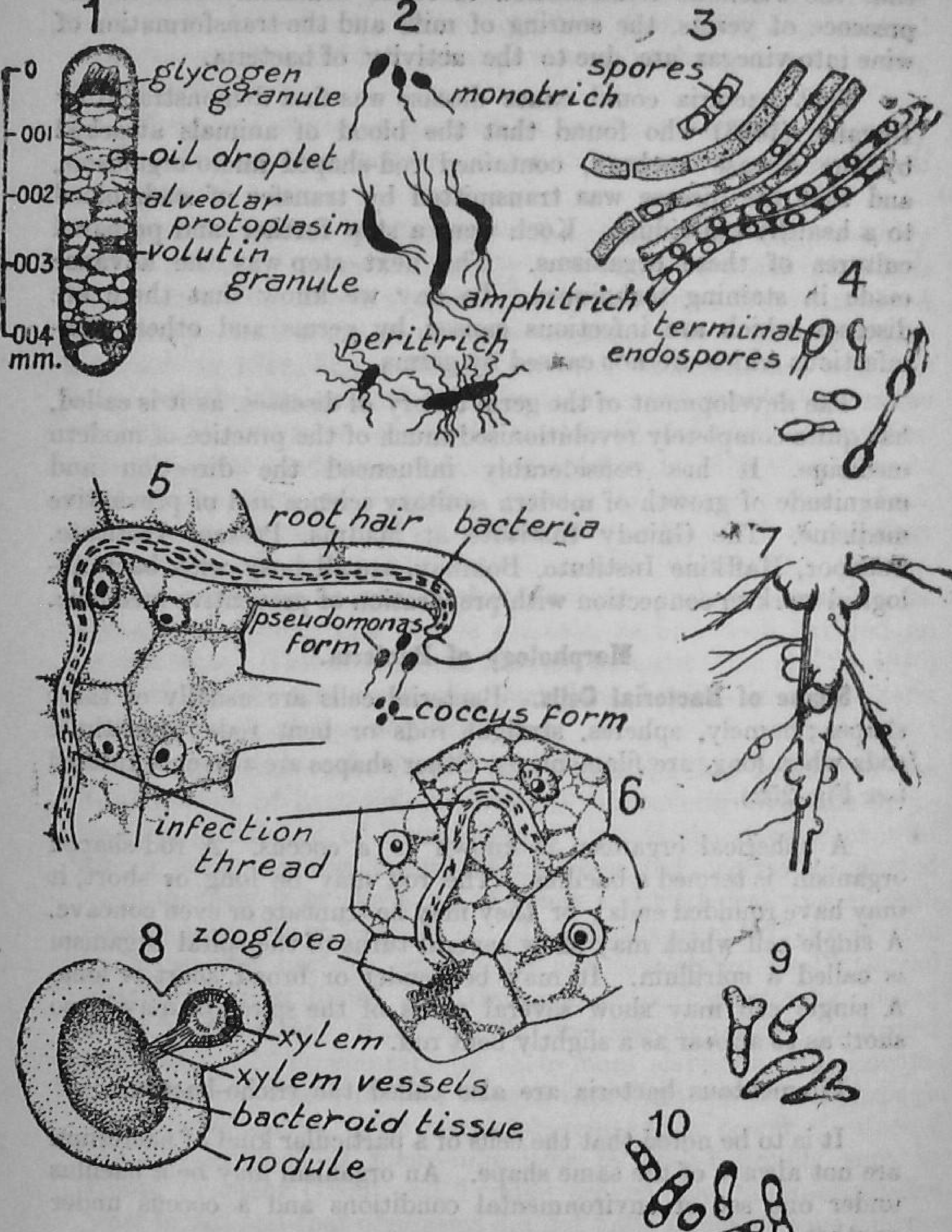


Fig. 252. *Bacteria.* Different forms including roof nodule formers.

arrangement within the group are determined largely by the manner of multiplication and the direction of the planes of division.

The cocci show the greatest diversity of cell arrangement (Fig. 252). Where the grouping resembles a chain of beads, it is known as a **streptococcus.** Sometimes they remain typically united in pairs and one of this type is termed a **diplococcus ;** when it is in clusters resembling grapes it is known as a **staphylococcus.**

Bacilli may remain united in chains. An organism producing such chains is sometimes termed a **streptobacillus.** Rod shaped bacteria may exhibit special groupings—loop forming, folding, etc.

Bacteria—size and measurements.—The unit used in measurement of microscopic objects is the micron, usually abbreviated as the Greek letter μ. The micron is the one-thousandth part of a millimeter or approximately one-twenty five-thousandth of an inch.

It has been noted that bacteria are of different shapes. They are of many different sizes. While a few species are large enough to be seen with a low magnification, there are others which are very minute as to be visible only under the highest magnifications of our microscopes. This means that some are less than 0·1 μ in diameter and there are others ranging from 0.5 μ and 2 μ in diameter. Judging from the minute size of the bacteria it may be roughly computed that it would require one trillion (one million million) to have a total volume of one cubic centimeter. From their minute size and the rapidity with which they multiply, it is not surprising therefore to find them in such large numbers under favourable conditions.

Structure of the Bacterial cell.—The cell structure is simpler and more punitive than that of the higher forms.

There is a cell wall which is a relatively firm membrane surrounding the contents or living matter. The cell wall composition is not the same in all bacteria. It may be cellulose, or hemi-cellulose, pectin or similar compounds related to the carbohydrates. Some bacteria do possess a cell wall resembling that of fungi.

The cell wall of bacteria is to be regarded as a protective membrane. The food taken passes through this wall by diffusion. It is probably not selective.

Cell contents.—The inner layer next to the wall is known as the ectoplast. This plays an important role in nutrition as it is a selective membrane. Bacterial cells also manifest plasmolysis like other plants though not so frequently. Whether a bacterial cell possesses a nucleus or not is still a controversial

subject. But evidences accumulated so far tend to prove that there is a simple nucleus as in the fungi. It is now believed that bacteria do possess chromosomes through whom they transmit their characters from generation to generation. Cell inclusions consist of metachromatic granules (diptheria bacillus), granules of glycogen (most bacteria), (*See* Fig. 252) sulphur granules (sulphur bacteria) and oil or fat globules.

Capsules and sheaths.—Some bacteria produce a thick gelatinous outer portion or covering for the cell wall. In most cases it is a thin capsule and in only a few it is thick and conspicuous. The capsule is usually partially soluble in water or at least swell greatly in it.

The capsule is not always easily demonstrated in a microscopic examination. Special staining methods are necessary.

In some cases the capsular material of cells forms a gelatinous mass in which the bacterial cells appear to be embedded. Such a collection of organisms together with the surrounding gelatined covering is termed a zoogl œa. In sewage and other highly contaminated water and decomposing food, etc., zoogl œa are always present.

Bacteria growing in chains sometimes secrete a firm membrane about the whole filament forming a tube, or sheath in which the organisms live. Compounds of iron or calcium may be deposited in this sheath.

Locomotion of Bacteria.—Most bacteria have the power of independent movement. This motility is due in many cases to the presence on the bacterial cells of one or more delicate, hair-like appendages termed flagella or whips. The flagella move actively in the water propelling the organism. They are very delicate, easily break off, and disintegrate, and are difficult to demonstrate. A few of cocci, many of bacilli and most of spirilla possess flagella and are motile.

An organism with a single flagellum at one end of the cell (polar) is **monotrichous** ; one with a cluster of two or more at one end is **Lopotrichous** ; one with a cluster **amphitrichous,** one with flagella on all sides **peritrichous** (Fg. 252). Some swim very much like a snake by sinuous bending of the cell body while some glide like the blue green algæ *oscillatoria.*

Reproduction of Bacteria.—Bacteria multiply very rapidly. The most common method is by fission, that is, by a transverse splitting of the cell into two. This is termed as a type of **vegetative reproduction** in contrast to spore production to be discussed later.

Sometimes bacteria bud from the cell surface and some produce reproductive bodies from internal segmentation. These are called **gonidia.** The bacteria which produce nodules on the roots of Leguminosæ reproduce by gonidia.

The motile cells enlarge and their contents become granular and several granules eventually occupy a cell. The cell wall then ruptures and the granules (gonidia) emerge as "swarming" or "swan" cells. Some bacteria produce specially resistant cells fitted to reproduce the species after a period unfavourable for growth. These cells are termed **spores.**

The rapidity of multiplication is of the greatest economic importance. For it enables bacterial cells, in spite of the slight bulk of a single organism, to produce very considerable chemical changes in a short time, as in fermentation. For example, milk, with an initial start of a very few bacteria capable of producing lactic acid, if allowed to stand in a warm place, will sour within a few hours.

Spore production.—Spores are produced by many bacteria because these are usually much more resistant to unfavourable conditions, such as drying, heat, light and chemical agents than are the cells which produce them. The spore has two advantages: (1) its membrane gives a better protection and (2) contains much less water than that of the vegetative cell.

The spores are of different kinds. It is termed an **endospore** when it is formed within a bacterial cell. They are known as **anthrospores** where as in certain cells of cocci when dried still retain the power to grow and are not differentiated from the vegetative cells but are more resistant. Some produce specialized spores called **conidia** (Fig. 252) when they are formed at the free tip of the filament.

Sexual reproduction.—There is reason to believe that sexual reproduction of a relatively punitive type does occur in some bacteria.

Classification of Bacteria.—Like the higher plants bacteria are also classified into families, genera and species.

CHAPTER XXVIII

THE ALGAE

Introduction.—The Algae are adapted for aquatic life, and they live mostly in water or in damp situations. Many of them live in fresh water, but a great majority live in the sea, constituting the great assemblage of plants known as **seaweeds.** They are most diverse in size, form and habit. Whatever their form and size, all of them possess well differentiated cells. Amongst the fresh water forms of Algae we can distinguish two distinct kinds, namely, the **Blue-green Algae** or **Cyanophyceae** and the **Green-Algae** or **Chlorophyceae.**

CYANOPHYCEAE OR BLUE-GREEN ALGAE.

General Structure.—The blue-green algae are easily distinguished from any other class of algae by their blue-green colouration, the lack of differentiation in the cell structure and in the reproductive organs and the presence of mucilaginous sheaths.

Distribution.—The Blue-green Algae are cosmopolitan occurring wherever there is a little moisture and are easily collected from storage tanks, sides of flower pots, drainage or irrigation channels, steps of tanks, bath room floor, etc. They occur in fresh and salt water, running and stagnant water, in arctic seas and hot springs.

Forms.—They are unicellular and often aggregated in colonies as in *Gloeocapsa* (Fig. 253) or multi-cellular and filamentous as in *Oscillaria* (*Oscillatoria*) and *Nostoc.* The cells contain protoplasm, but without any well defined nucleus. By careful fixing and staining of these plants, it is possible to make out certain diffuse granular bodies of the nature of chromosomes in the centre of protoplasm in every cell. This may be considered an incipient nucleus. The blue-green colouration is not very deep under higher magnification, but very light. The granulation of the protoplasm is not easily visible. True vacuoles are absent but "pseudo-vacuoles" are sometimes present. In some filamentous Cyanophyceae, there appear at certain intervals special, enlarged, colourless cells with thickened walls; these are called **heterocysts.** These are cylindrical in shape and have lost their power of growth; their walls are slightly thickened at the

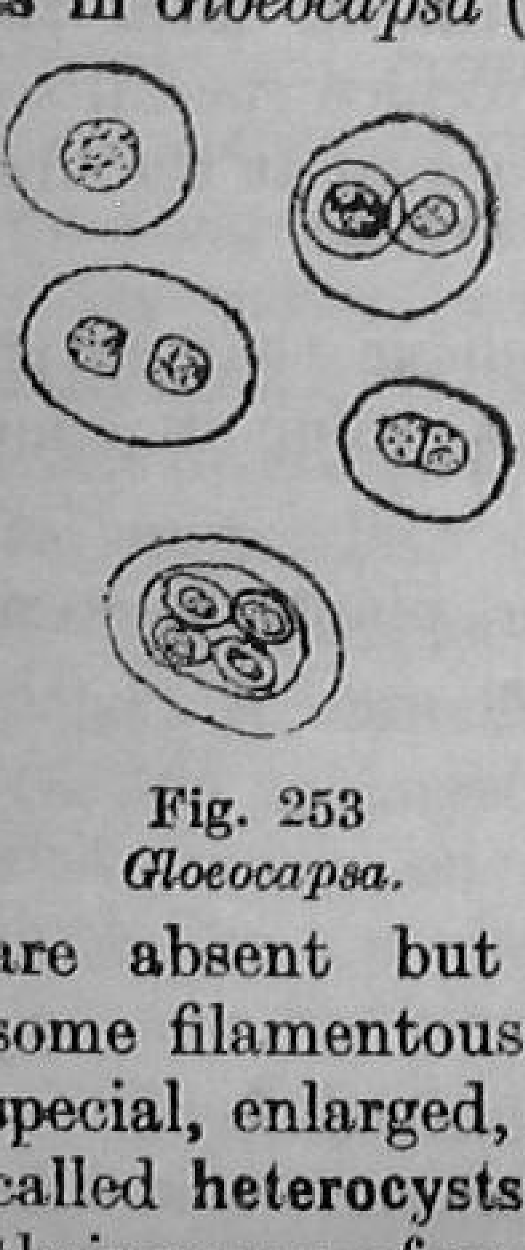


Fig. 253
Gloeocapsa.

poles. The function of **heterocysts** is not clear. It is believed that their function is to delimit the length of the filaments, so that the latter may be easily broken up into pieces "**hormogonia**"—which serve for vegetative reproduction. This is best noticed in *Nostoc* which can be collected in the rainy season near about tanks or in grass lawns. There are other views also expressed with regard to the function of the hormogonia organs.

Nutrition.—Blue-green Algae are **autotrophic** or independent organisms which manufacture their carbohydrates by means of chlorophyll and light. The products of assimilation are certain sugars, glycogen and oil; the end products phycoproteins; some species of cyanophyceae live **endophytically** in other plants. *Nostoc* is an example of this type. Others live symbiotically with fungi to form the lichen organism.

Reproduction takes place in one or other following ways:

(1) By **Cell division** or **fission** in unicellular types. There is no chromosome or spindle formation.

(2) By **Hormogonia,** i.e., fragmentation of the filament at the region of the heterocyst as in *Nostoc.* The separation of the filaments may also be effected by the death of the intervening cells.

(3) By **Resting spores (akinetes).**—The resting cells are formed of ordinary vegetative cells where food is accumulated and the walls considerably thickened. The resting spores are formed during times when conditions for life are very unfavourable. They keep their vitality for a long time and with the return of favourable conditions germinate into new plants.

TYPES.

(1) *Oscillaria* (*Oscillatoria*).—This is a filamentous, very common blue-green algae, simple or sometimes spuriously branched, occurring singly or in strata, chiefly in dirty water with decaying material, also on wet floors, damp walls, etc. (Fig. 254). The filament has a mucilaginous sheath especially when the plant is young. The apical cell is slightly conical or convex while the rest are cylindrical and similar in size and structure. The transverse or *discoid* walls are often obscure. Heterocysts are absent. Reproduction is by fragmentation of the filament.

Movement.—A characteristic feature of this plant from which it derives its name, is its slow swaying or 'oscillating' movement. As the plant creeps or glides along the substratum, it sways from one side to the other and exhibits at the same time a slow rotating and nodding movement in the forward directed end. This can

be made out easily under the microscope. Though the exact reasons for the movement are not known, it is seen that they are accelerated by an increase in temperature and the intensity of light.

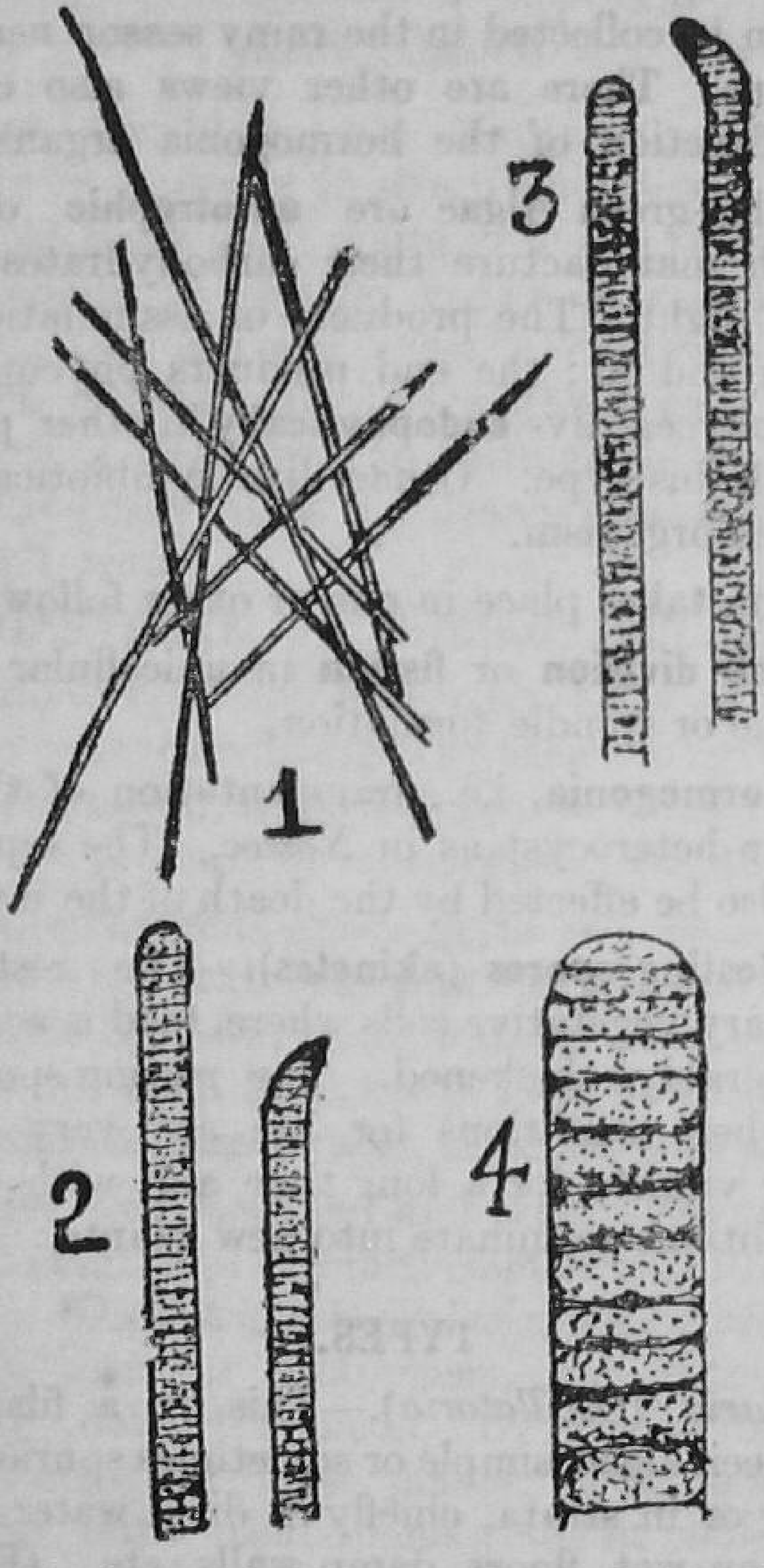


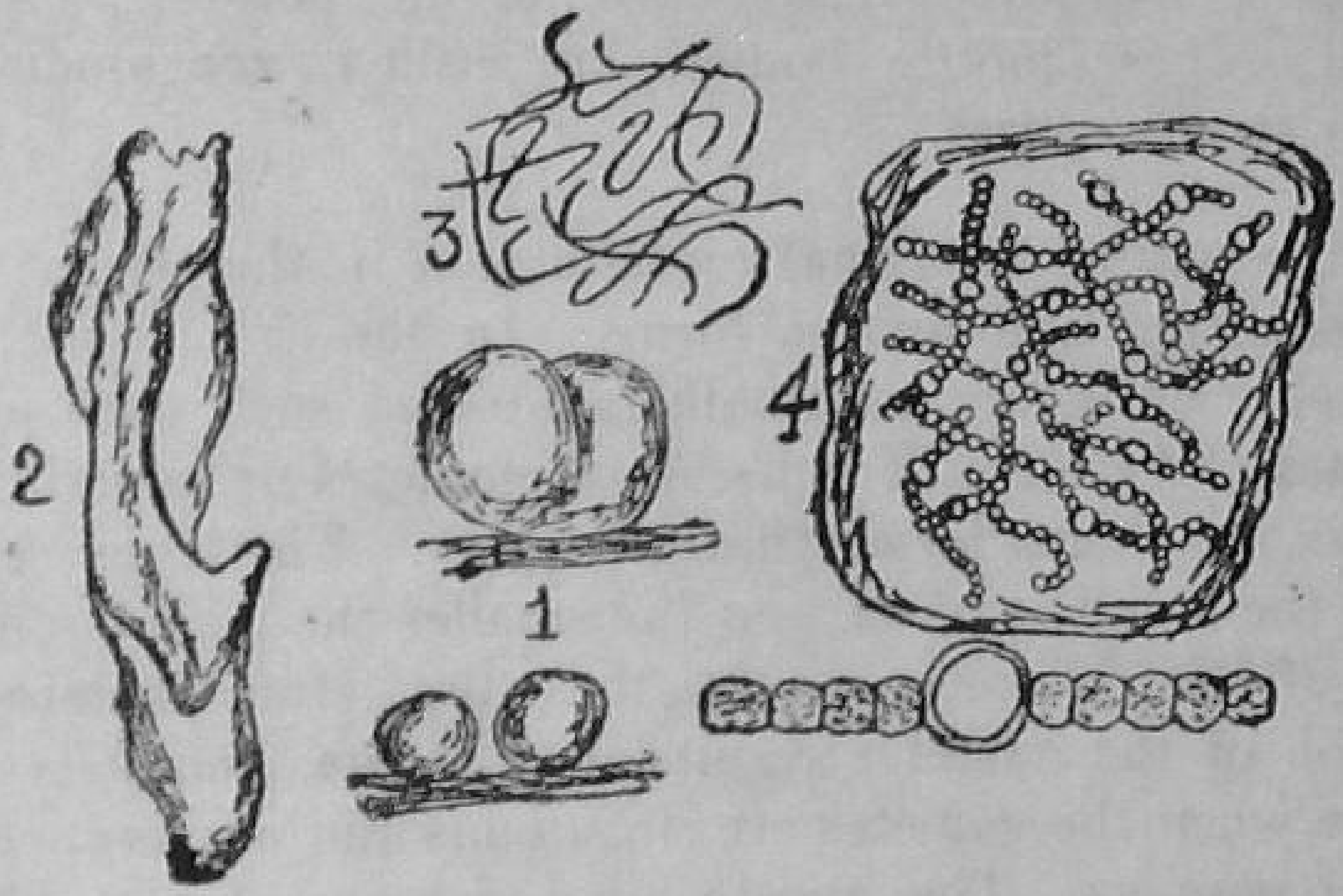
Fig. 254. 1 & 2. Two species of *Oscillatoria*. 3. slightly magnified. 4. highly magnified.

(2) *Nostoc*.—*Nostoc* plants are easily collected after a rain or when the tank is getting dry. (Fig. 255). Some species of *Nostoc* live endophytically in the intercellular spaces of other plants such as *Anthoceros*, *Lemna* and root tubercles of *Cycas*. A few unite with fungi to form lichens.

CHLOROPHYCEAE.

The Green Algae is a wider group consisting of a larger number of families, genera and species than the Cyanophyceae. The

chloroplasts are bright, green, large and variously shaped. They are usually peripheral in position in the protoplast. These plants attain their greatest development in fresh water, and they are most diverse in their cytological structure and life-history.



Fig, 255, *Nostoc.* 1 and 2. masses of *Nostoc* filaments (Natural Size); 3. filaments as seen under low power 4. filaments magnified.

There are many Green Algae that are unicellular and these are the primitive forms of the group. In some plants the whole of the thallus consists of the so-called single cell, but really an aggregate of protoplasts with a common cell wall. Such plants, as already stated, are described as **coenocytic.** Amongst the multicellular forms, we find the thallus developing into simple or branched filaments, colonies, flat expansions or into masses of tissue.

All the cells are provided with chloroplasts, and a nucleus is found in every cell.

Reproduction.—Naturally, in unicellular Algae multiplication is effected by cell division, and in the filamentous forms this occurs by fragmentation of the filaments. Propagation is effected in most of the lower Algae by vegetative reproduction by cell division or fragmentation, and the higher forms multiply themselves by means of spores formed asexually or sexually. The occurrence of sexual reproduction or asexual reproduction seems to be dependent largely on external conditions. Both spores and sexual organs may be formed on the same plant, but they are usually found at different times. It may be stated generallly that when conditions of growth are favourable a sexual reproduction occurs; and sexual reproduction takes place, when conditions are adverse for growth.

Asexual reproduction is effected by the formation of spores, which may be motile or non-motile. In some cases the contents of a cell become transformed into a resting spore. But often the protoplasm of a single cell changes by rejuvenescence into a single motile spore. In some Algae instead of one spore many are formed in a cell. These motile bodies are called **zoogonidia** or **zoospores** or **swarm spores.**

In the matter of sexual reproduction in the Green Algae we have interesting and unique forms. In the first place, we have sexual cells which are externally alike and such ones are called **Isogametes.** We have in some Algae gametes or sexual cells that are unlike, one being larger than the other. The larger sexual cell is called the female gamete and the smaller the male gamete. On account of this difference in size these are termed **heterogametes.** The union of the gametes results in a **zygote,** and it is called a **zygospore** when the gametes are isogamous and **oospore** when they are heterogamous. The zygote may develop directly into the plant, or it may become divided into zoospores, each of which then grows into an individual plant.

The following Green Algae, *Chlamydomonas*, *Spirogyra*, *Zygnema*, and the *Desmids* are treated below:

Volvocales.—The volvocales are the only Chlorophyceae in which the vegetative cells are flagellated and actively motile. The cells may be solitary or united in colonies of definite form and with a definite number of cells. Asexual reproduction is by the formation of zoospores or by the formation of motile daughter colonies. Most genera reproduce sexually, and gametic union range from isogamy to oogamy. All are fresh water in habit. The following common genera are described: *Chlamydomonas*, *Pandorina*, *Eudorina*, *Pleodorina*, and *Volvox*.

Chlamydomonas.—This may be considered as the simplest type of plant organism in the group Green Algae of the Thallo phyta. It occurs abundantly in rain-water pools or collections.

Morphology.—It consists of a single microscopic ovoid or oblong cell from one end of which projects two long thin threads of protoplasm, the cilia or flagella, which by a rapid lashing movement propel the cell swiftly through the water, the cell rotating meanwhile about its long axis (FIG. 256). A thick cellulose wall encloses the protoplasm and it thickens out at the forward end from which the cilia project. At this end also, just within the wall and in close

contact with the cilia, are two "**contractile-vacuoles**" which by their alternate expansion and contraction are supposed to cause the flagellate movements. Close to these and also just within the cell-wall, is a red "**Eye-spot**" containing the pigment. This eye spot is often sensitive to light and is regarded as controlling in some way the direction of movement of the organism. There is a nucleus

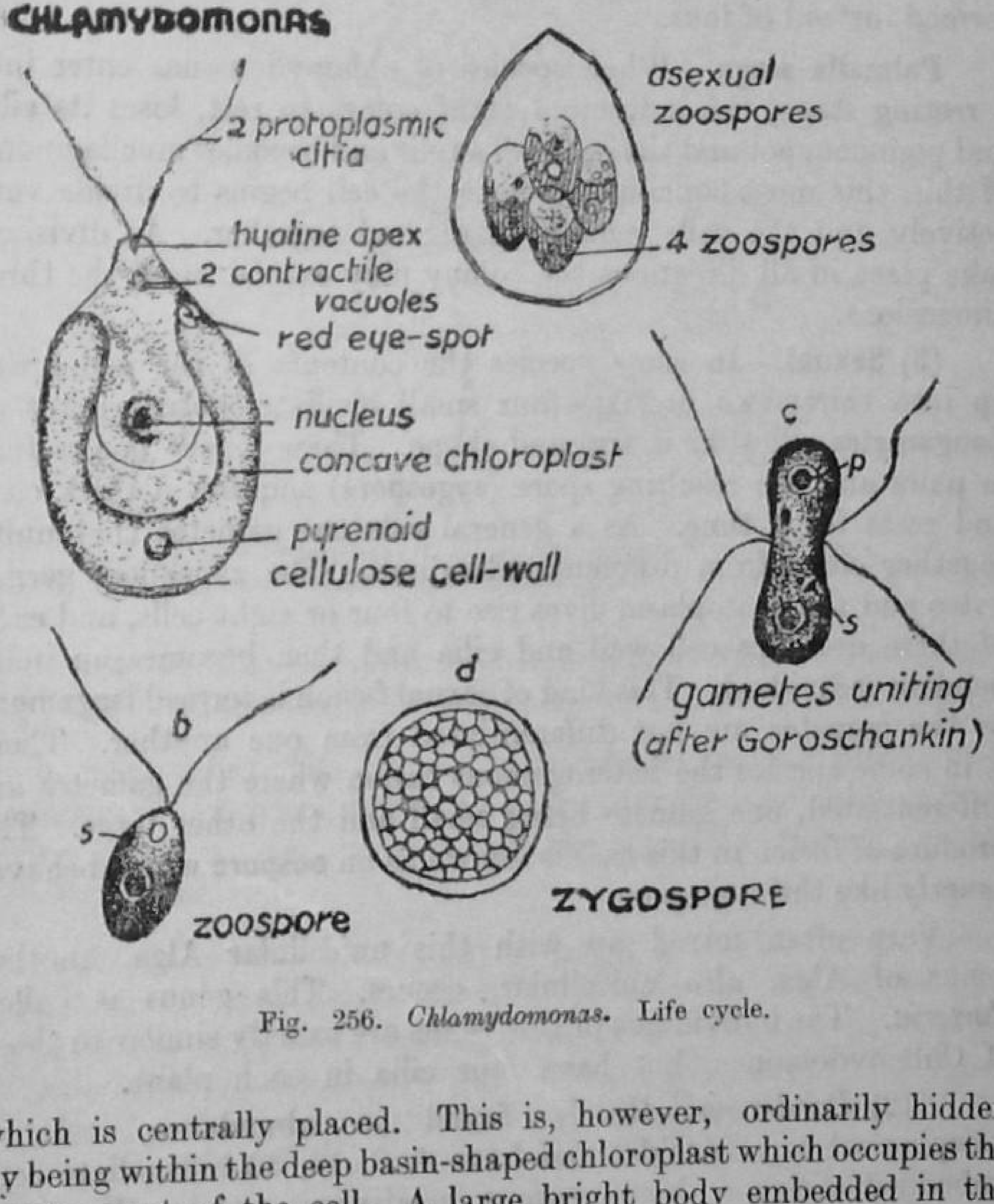


Fig. 256. *Chlamydomonas*. Life cycle.

which is centrally placed. This is, however, ordinarily hidden by being within the deep basin-shaped chloroplast which occupies the greater part of the cell. A large bright body embedded in the chloroplast, which might at first be taken for the nucleus is the "**pyrenoid,**" a body which is concerned with starch formation. The plant is able to manufacture its own food as it has chloroplast and is therefore independent. *Chlamydomonas* thus differs from a simple animal organism like *Amoeba* in being able to manufacture its own food from raw materials like carbon-disxide, a few other

salts and water in the presence of sunlight. The resemblance to the animal is in its capacity to move about.

Reproduction.—(a) **Asexual.**—When plants of chlamydomonas are allowed to grow in a culture solution, the contents of the cell become divided into four ovoid cells by division. These four inner cells sooner or later begin to move within the large cell and finally escape as **Zoogonidia** which swim about, settle down and develop into *Chlamydomonas* plants. Sometimes eight zoogonidia are formed instead of four.

Palmella stage.—When species of chlamydomonas enter into a resting stage, the individual plant comes to rest, loses its cilia and pigment spot and the cell wall swells and becomes mucilaginous. Within this muscilaginous envelope the cell begins to divide very actively and the cells remain aggregated together. As divisions take place in all directions the colony may extend in all the three dimensions.

(b) **Sexual.**—In some species the contents of the cell break up into thirty-two or sixty-four small biciliate motile spores or **Zoogametes,** all alike in size and shape. These motile bodies fuse in pairs and the resulting spore (**zygospore**) acquires a thick coat and rests for a time. As a general rule the gametes that unite together come from different individuals. The zygospore germinates and the protoplasm gives rise to four or eight cells, and each of these develops cell wall and cilia and then becomes an independent individual. This kind of sexual fusion is termed **isogamous** as the gametes are not differentiated from one another. There is in some species the heterogamous fusion where the gametes are differentiated, one gamete being small and the other large. The product of fusion in this case is known as an **oospore** which behaves exactly like the zygospore.

Very often mixed up with this unicellular Alga, another genus of Alga, also unicellular, occurs. This genus is called ***Carteria.*** The individuals of this genus are exactly similar to those of Chlamydomonas, but have four cilia in each plant.

(2) *Pandorina.*—Rarely found in abundance, colonies subspherical to ellipsoidal and have 4, 8, 16, 32 biflagellate cells embedded within a homogeneous gelatinous matrix (Fig. 258). The cells are arranged in a hollow sphere within the colonial envelope and are generally close together. Laterally abutting cells are pyriform and biflagellate, the eyespot borne at the anterior end. As in *Chlamydomonas* there are two contractile vacuoles at the base of the flagella, chloroplast massive and cup-shaped, pyrenoids one or more.

Reproduction : Asexual.—Every cell of the colony rounds off, separates from the adjoining cells. The protoplast of the cell now

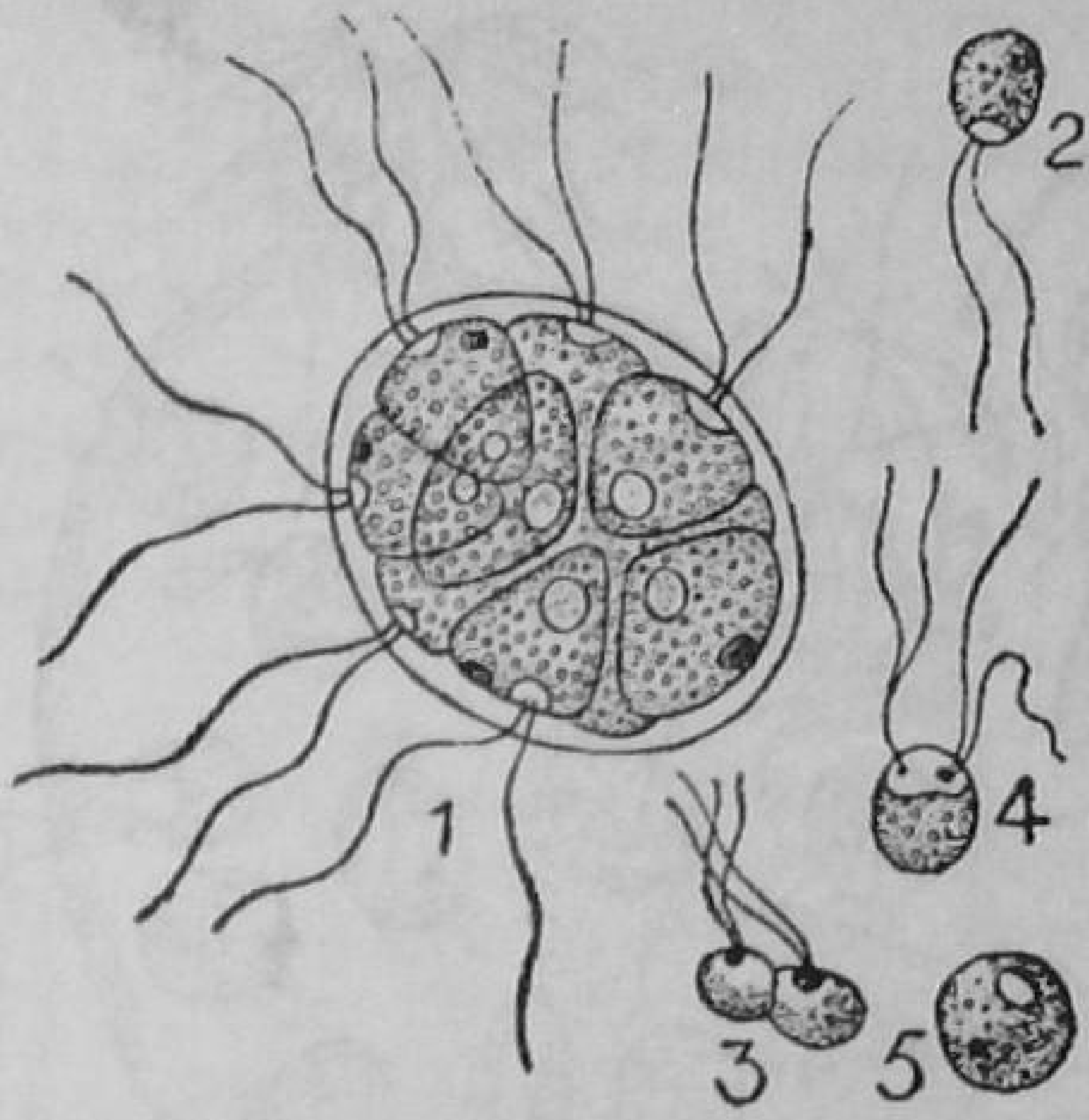


Fig. 257 **Pandorina** : 1. Swimming colony; 2. A Gamete; 3. Fusion Gamete; 4. Fusion complete; 5. Zygospore.

divides into as many daughter cells as is characteristic of the species 4, 8, 16 or 32 that form the daughter colonies in the mother colony.

Sexual—When the sexual reproduction takes place, the gametes are produced just as are the daughter colonies. The pairing gametes are similar and the sexually formed spore is a zygospore.

(3) *Eudorina.*—The colony is larger here (Fig. 259). New colonies are formed as described for *Pandorina*, but sexual reproduction is different. Certain cells of the colony, not much different from the vegetative cells, assume the function of **eggs.** Other cells divide to form groups of **sperms,** which hang together in a plate but finally break up and fuse with the eggs. Since the pairing gametes are dissimilar, this is a case of heterogamy. The product of fertilisation is an oospore.

(4) *Volvox* is met with in temporary and permanant fresh water pools. The water becomes green when they are in abundance. The free swimming colony is a hollow sphere, the number of cells in a colony varying from 500 to 40,000. Each cell has its gelatinous sheath. The outer cells are flagellate.

Reproduction.—Some of the central and posterior cells become large and these are the reproductive cells for asexual or sexual

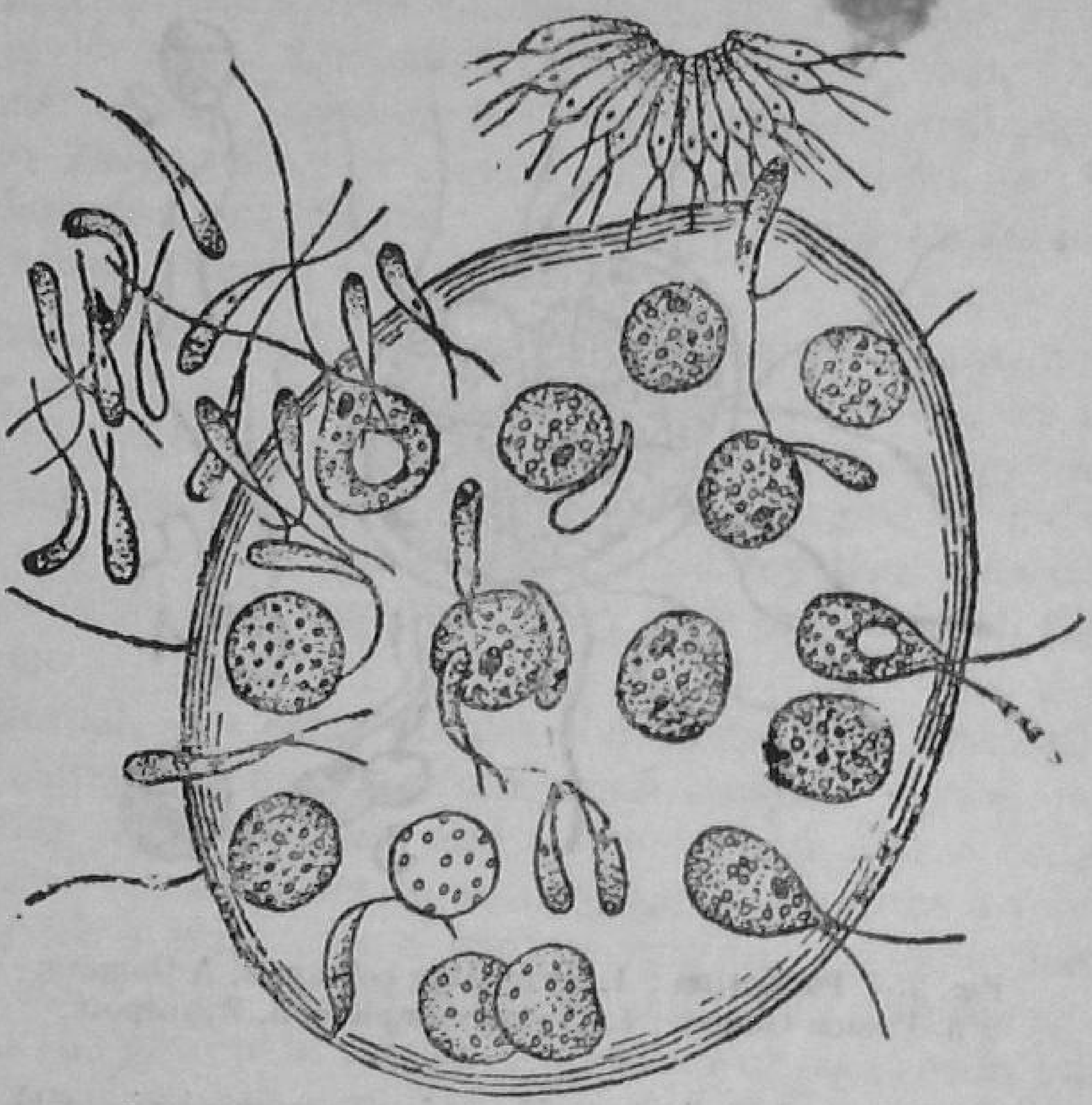


Fig 258 **Eudorina** : Note the colony cells functioning as egg with which sperms come into contact.

purposes. In fact all reproductive cells of a colony are exclusively sexual in the beginning of the growing season and exclusively sexual at the end of the season. Colonies formed escape by being inverted in just the same way a glove or a sack is opened out. For asexual purposes, 5 to 20 cells generally become reproductive. Sexual reproduction is oogamous, and may be **homothallic** or **heterothallic.** The sexual organs—the male (**antheridia**) produce the antherozoids which are liberated in a definite colony-like mass and the whole mass swims until it reaches the egg. The **oogonium** is non-flagellated, single and spherical. The zygote has a stellate wall and remains viable for several years. Before germination, reduction division occurs.

(5) *Pleodorina.*—A rare form found in fresh water. The colony is spherical, contains 64 or 128 cells which are arranged in no special manner near the periphery. The alga is of special interest in having numerous gonidial cells interspersed among somatic cells. One part of the colony—the anterior part—is free

from gonidia. The cell structure is similar to that of *Pandorina* and *Eudorina*.

The cells of the young colonies are all equal in size and contain a single pyrenoid and all the cells exhibit uniform increase in size up to a certain stage. Then the somatic cells cease to grow and only those continue to enlarge which are to become gonidia. The pyrenoids increase in the gonidial cells.

The life history of the alga is similar to that of Pandorina and Eudorina.

Zygnematales.—*Spirogyra*, *Zygnema* and the *Desmids* come under this group.

Spirogyra.—This genus is best known, and it is commonly found in ponds, ditches, streams and rivers, forming unattached masses of tangled green slimy filaments on the surface of water. They are buoyed up by the numerous bubbles of oxygen caught in the tangled mass of filaments. (Fig. 259.) The filaments feel slimy to the touch as they are invested by thin mucilaginous sheaths.

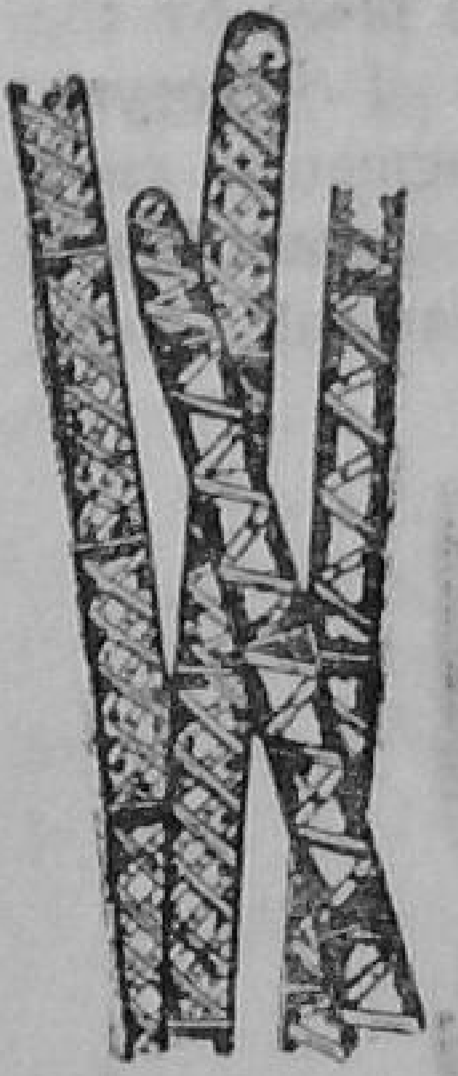


Fig. 259. Filament of different species of *Spirogyra;* slightly magnified.

Morphology.—When viewed under the microscope, the filament is very attractive on account of the spirally disposed bandlike chloroplast. In some species of *Spirogyra* we find only one band of chloroplast, whilst in others we may have two, three or more upto 12 or even 14. The spirals may be very close or they may be far apart, and in some they are practically straight and longitudinal.

The filament is simple in its structure, without any distinction into base and apex. Each filament consists of a series of cylindrical cells which are longer than broad. All the cells have the same structure.

The cell wall is fairly thick and the transverse partitions between the cells are straight. A thin layer of protoplasm forms a lining to the cell wall in each cell and encloses a large central vacuole. In the median portion of the cell is suspended a **nucleus** which is embedded in a small amount of cytoplasm. From this cytoplasm numerous protoplasmic strands radiate and join the peripheral protoplasmic layer. On close inspection it would be seen that each of these strands joins the protoplasmic layer just opposite the pyrenoid body found in the band of chlorophyll. (Fig. 260.) The shape of the nucleus is ellipsoidal in some species,

and it is globular in others. The spirally disposed band-like chloroplasts are peripheral in position. In these bands of chloroplasts small refractive bodies, the **Pyrenoids**, occur at intervals. Starch grains are usually found aggregated around these bodies.

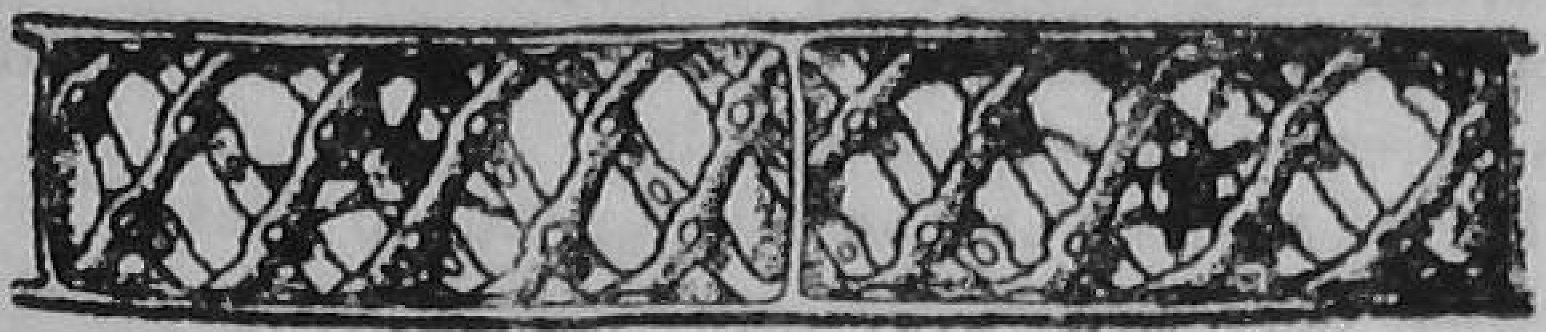


Fig. 260. *Spirogyra* filament showing the nucleus and the chloroplasts in their cells. Highly magnified.

Reproduction Asexual.—Propagation may take place by the vegetative method of reproduction. The filaments of *Spirogyra*, like other filamentous Algae, may break into fragments, each fragment consisting of one or more cells. Each separate bit is capable of cell division and growth into a long filament. Very often by this method *Spirogyra* spreads widely.

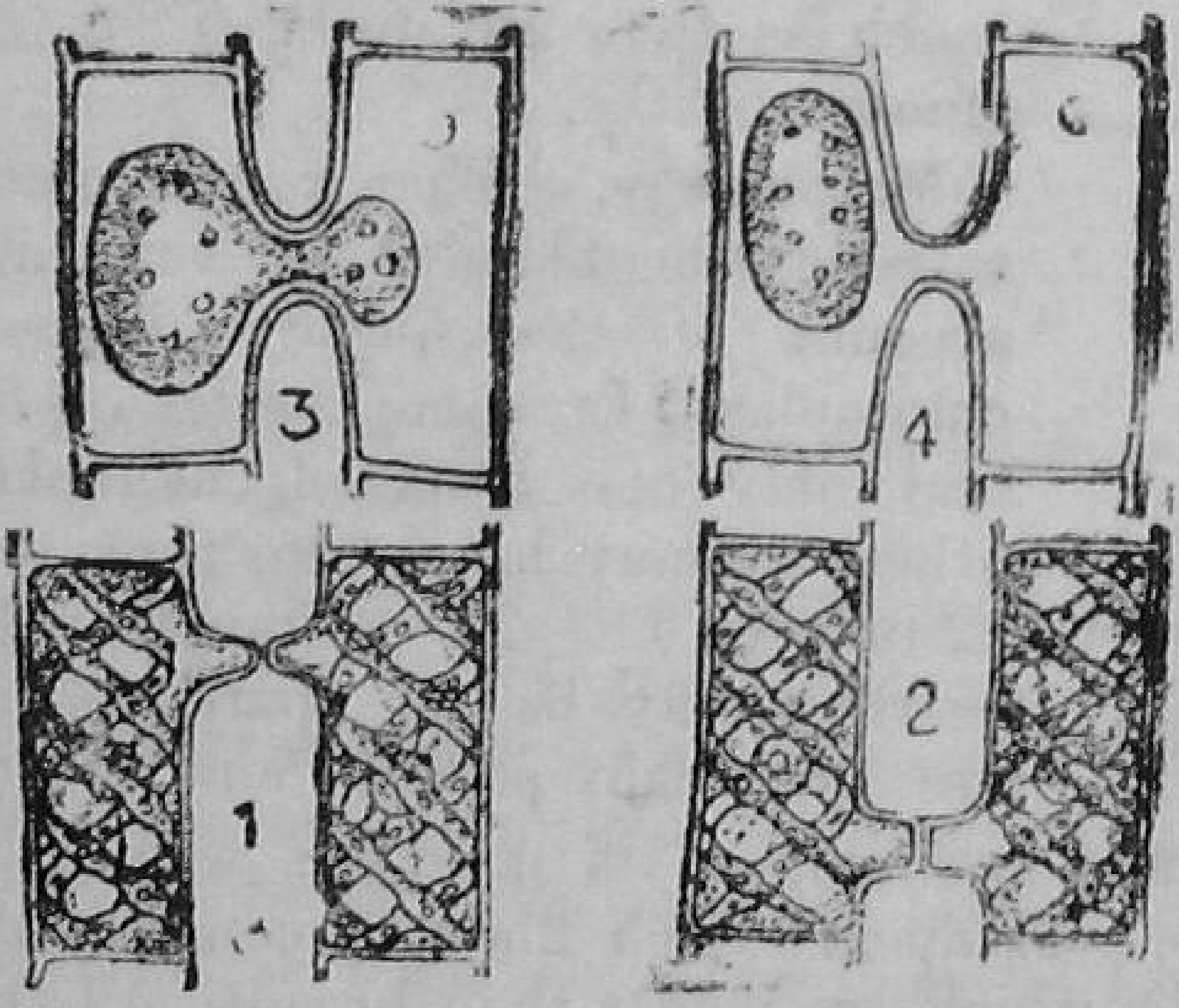


Fig. 261. Conjugation in *Spirogyra* and Zygotes in the female filament, 1 and 2 filaments with the fusion tube just meeting; 3. filaments with the Zygote just forming; 4. filaments with the Zygote fully formed. Highly magnified.

Sexual.—In addition to vegetative propagation, it reproduces itself by a kind of sexual reproductive process called **conjugation.** (Fig. 261.) If old discoloured filaments are examined, there will be found some filaments arranged in pairs, the two being connected together by tubes passing from a cell of one filament to a cell opposite to it in the other. In the cells of one of the filaments oval bodies will be seen, and none in the other. Each of these bodies is

a zygote capable of germinating and developing into a *Spirogyra* filament.

The process of conjugation occurring in *Spirogyra* is as described below. Two filaments of this plant come close together and lie parallel to each other. Small processes arise simultaneously in the cells of the filaments that are opposite to one another. These two processes meet and after fusion, a free passage is formed between the two cells. Then the protoplasm in one of the cells shrinks away from the cell wall and moves towards the connecting tube. The protoplasm in the opposite cell also gets separated from the cell wall and becomes somewhat rounded. The mass which passes into the passage finally enters the opposite cell and the two masses of protoplasm fuse to form the zygote. During fusion the chloroplast of the cell which passes through the connecting tube degenerates. While still young the nucleus of the zygote seems to undergo division into four cells, and only one of these persists. During this process reduction in the number of the chromosomes takes place.

Although the gametes are non-motile and simple in *Spirogyra*, the beginning of differentiation into sexes is somewhat apparent. The cell containing the zygote may be considered to be the female and the other from which the protoplast moves through the passage the male cell.

The genus *Spirogyra* belongs to an extremely well-defined group Conjugata. This is one of the most natural groups of the Green Algae.

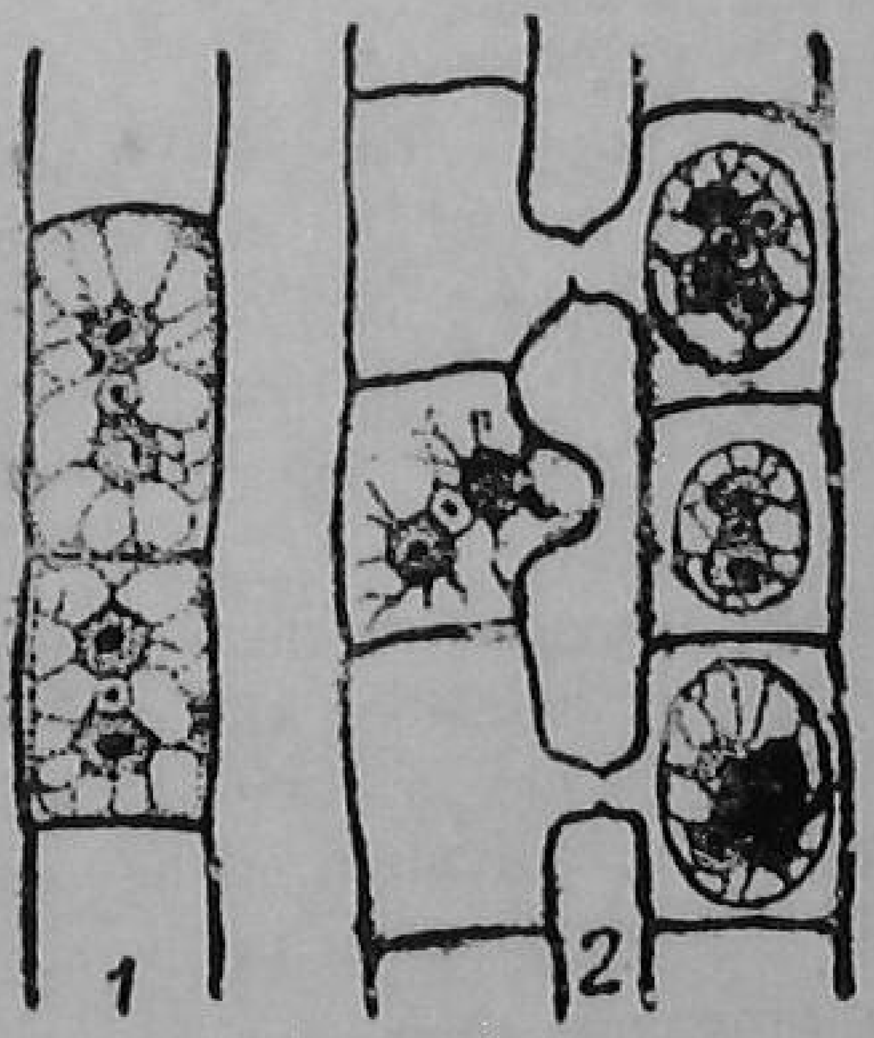


Fig. 262. Zygnema. 1. Filament. 2. Conjugation.

Zygnema is unbranched and filamentous occurring in fresh water and very common like *Spirogyra*. *Zygnema* has cells with two stellate chloroplasts which have numerous delicate to massive strands extending to the plasma membrane (Fig. 262). There is a single pyrenoid for each chloroplast. The cells are cylindric and uninucleate. The cell division is mitotic and each daughter cell receives one of the chloroplasts of the parent cell.

Reproduction.—Vegetative reproduction is by fragmentation of the filament. Sexual reproduction is by *conjugation*, very much

like what takes place in *Spirogyra.* Conjugation here is usually scalariform. The nucleus of the zygote undergoes a reduction division before germination.

DESMIDS.

The Desmids, though unicellular, are very interesting forms, because of their great diversity in form and wonderful symmetry.

Some of them are indeed the most beautiful microscopic objects. (Fig. 263.) These Algae occur as floating forms in great

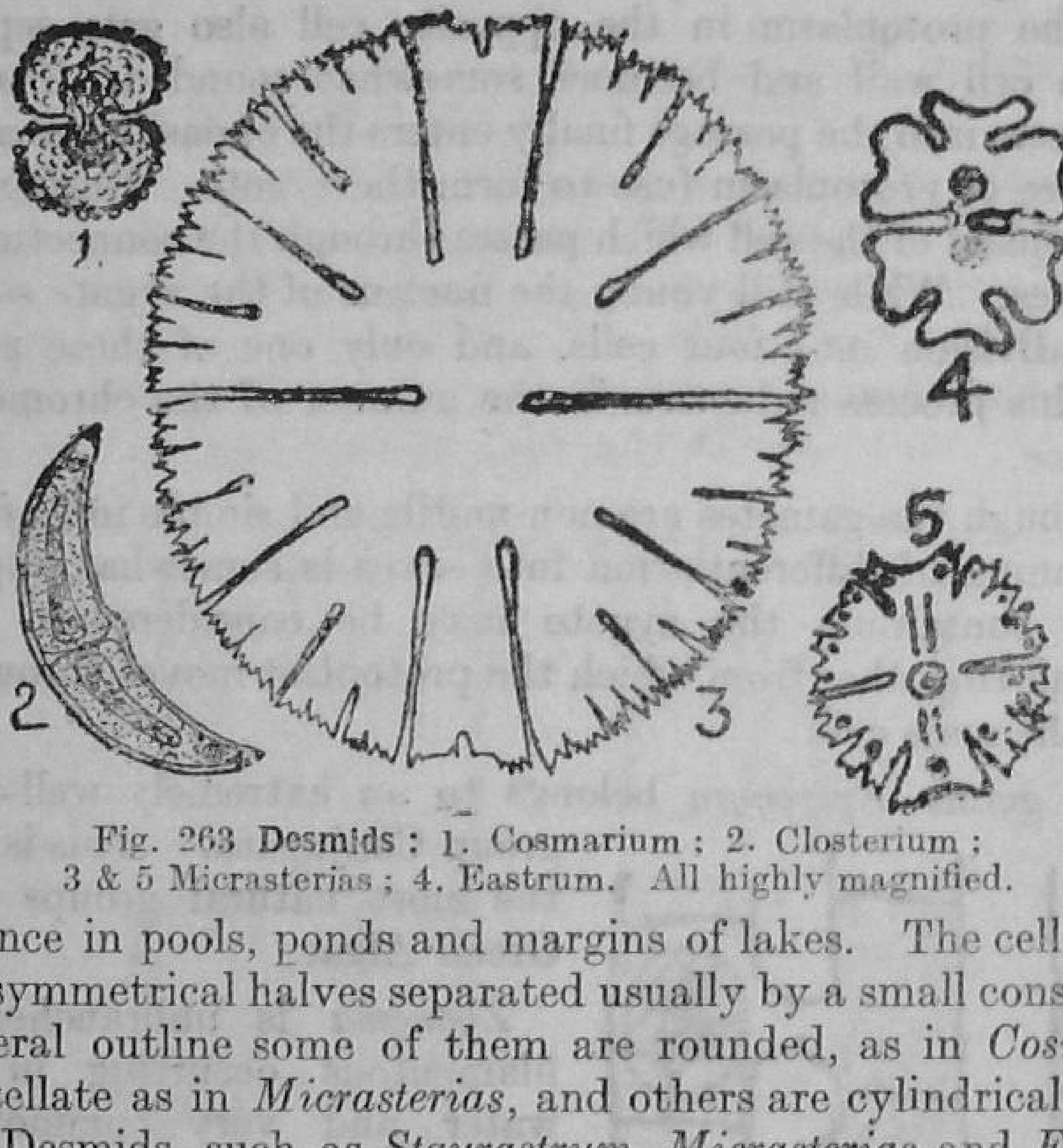


Fig. 263 **Desmids :** 1. Cosmarium ; 2. Closterium ; 3 & 5 Micrasterias ; 4. Eastrum. All highly magnified.

abundance in pools, ponds and margins of lakes. The cell consists of two symmetrical halves separated usually by a small constriction. In general outline some of them are rounded, as in *Cosmarium*, some stellate as in *Micrasterias*, and others are cylindrical. Some of the Desmids such as *Staurastrum*, *Micrasterias* and *Euastrum* present the most complicated forms of outline.

Morphology.—The protoplasts are provided with a single nucleus in each individual and it is usually lodged in the middle of the cell. The chloroplasts are large and are of some definite form, conforming to the general shape of the individual. They are either central or parietal in position. Pyrenoids occur in them.

Reproduction.—Desmids usually propagate themselves vegetatively by simple cell division. Sexual reproduction is occasionally met with amongst them. Two individuals approach each other and they remain close together by the formation of a mucilaginous sheath. The protoplasts from these two cells escape, fuse and form a zygote. No tube is formed between the two individuals.

The conjugating gametes cannot be distinguished from each other. The zygospore forms three coats; the first or innermost being of cellulose, the second thick and brownish and the third external one warty or spiny. Owing to these outgrowths zygospores are generally very striking.

Species of *Cosmarium Euastrum* and *Staurastrum* are commonly met with in ponds and lakes.

Oedogonium.—Several species of *Oedogonium* are found in ponds, puddles and in running water, also epiphytic on other organisms, very commonly *chara.* (Fig. 264.) The plant consists of unbranched simple filament with well-marked *haptera* or organs of attachment at the base when young, although these filament floats freely in the adult stage. The filaments vary in thickness very much according to the species.

The filaments are usually rigid, uneven in thickness and without any mucilaginous sheath. Each filament terminates at the apex either by a rounded cone or by an attenuated process. The cells composing the filaments are all cylindrical, with the apical part of each cell slightly wider than the basal part, thus showing the distinction between the base and the apex even in the cells. The cell wall of cellulose encloses a cytoplasmic layer adhering to it, and a nucleus is imbedded in the centre of the cytoplasm. In the cytoplasm of every cell, there lies peripherally a reticulate chloroplast, and in this a number of pyrenoid bodies occur.

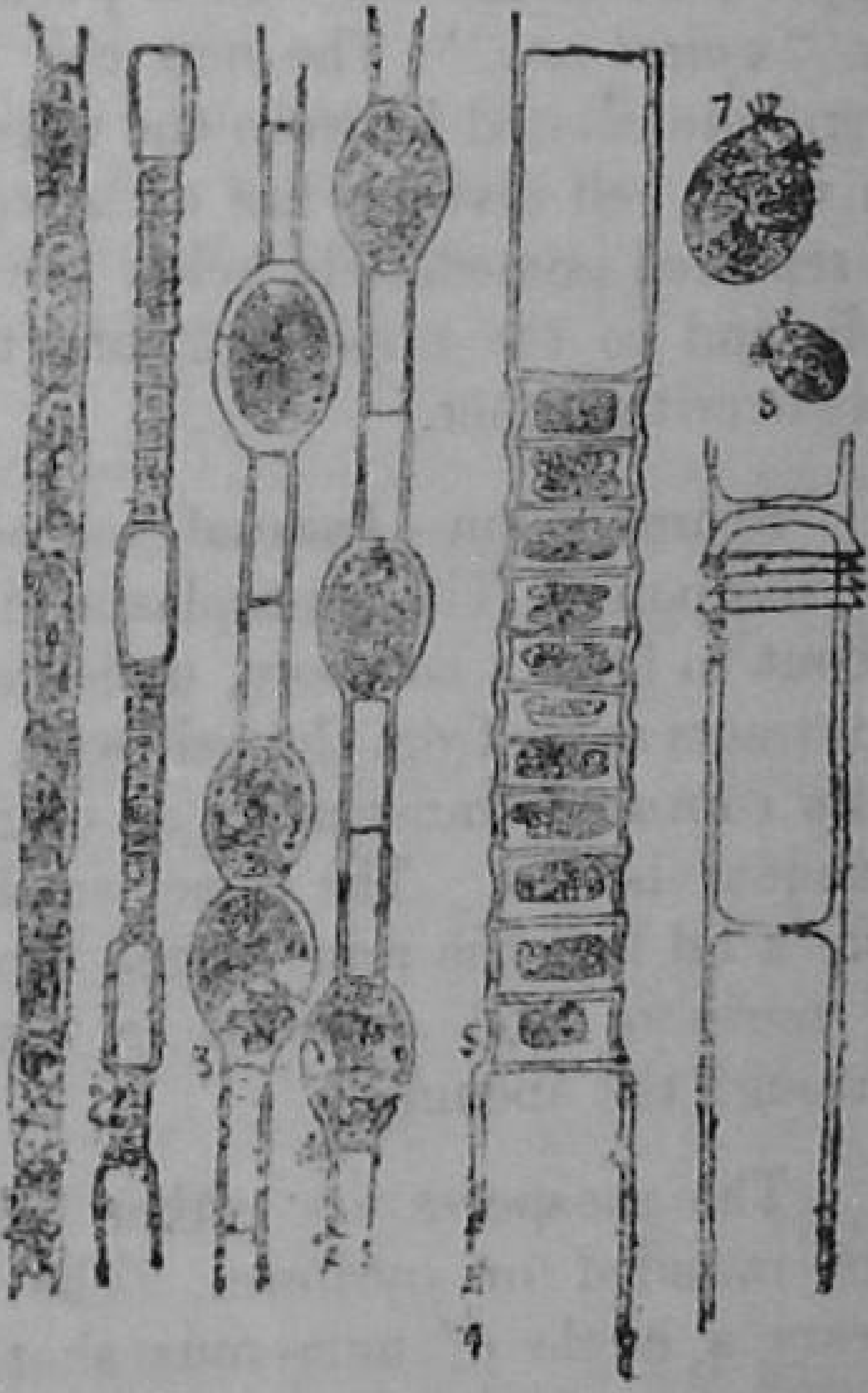


Fig. 264. **Odegoniuim** : 1. Filament 2. Antheridia in a filament ; 3 & 4. oogonia ; 5. Antheridia ; 6. Cell dividing ; 7. Zoospore ; 8. Antherozoid slightly magnified ; 5, 6, 7 & 8. slightly magnified.

The Oedogonium filaments grow in length by the division of the cells of the filament. But the cell division is of a kind quite characteristic of the genus. In many species of Oedogonium we find sometimes a number of transverse striations in the upper parts of some of the cells forming the filament. These striations

or the so-called "*apical caps*" are due to repeated cell division taking place in the same cell. All the cells except the basal cell are capable of division. In a cell which is about to divide, the nucleus at first undergoes division into two daughter nuclei, and, at about the same time, a ring-like thickening of cellulose is formed inside the cell wall at the apex of the cell. This cellulose cushion is connected with the cell wall both above and below. Exactly opposite to the thickening in the cell wall, the cell wall of the cell becomes torn all round externally. The slit thus caused all round is closed by the intercalary growth of the ring-like cushion into a cell wall membrane. Between the two daughter nuclei a transverse septum is formed which extends to the outer cell wall dividing the cell into two. By the intercalary growth of the cushion, now forming a portion of the cell wall of the newly formed cell, the upper part of the old wall is pushed upwards and this persists as an "*apical cap*." The new cell formed in this manner is as it were intercalated between the upper and lower portions of the cell in which cell division has occurred. This process of cell division is repeated immediately below the septum at the upper end of the cell, and so the upper portions persisting look like caps placed one over the other.

Reproduction—Asexual reproduction takes place by means of zoospores. The protoplasm of a cell of the filament, which is about to form a zoospore, undergoes rejuvenescence and gradually contracts away from the cell wall. In the meanwhile the cell wall gets ruptured transversely at or near the upper end into two very unequal halves. The upper small portion of the cell is lifted up like a lid and the rejuvenated protoplast, now transformed into a zoospore and enclosed in a delicate hyaline vesicle, escapes through the opening.

The zoospores are rather large and unique. In shape they are rounded or pyriform. The anterior end is colourless and bears a circle of numerous short cilia. In some species a red pigment spot also is present at the anterior end. The zoospore moves about for a short time and then attaches itself to the substratum by its hyaline end, losing all the cilia. The attached end develops into a *hapteron* and a cell wall is formed, and then it grows into a filament.

Sexual reproduction in *Oedogonium* is of a very high type and the specialisation of a male and the female organs is greater than in any other *Algae*, except in *Characeae*. In this specialisation it approaches *Bryophyta*. The female sexual organ or oogonium

is formed from a vegetative cell. The cell which is destined to become an **oogonium** divides into two unequal cells when it is about to become an oogonium. The lower cell which is smaller is the stalk-cell and the upper larger cell develops into an oogonium. When fully formed the oogonia are spherical or ovoidal. The large sexual cell or the female gamete in the oogonium is passive and never leaves the filament. The oogonia occur singly or in a series of 2 or more according to the species.

The male gametes or **antherozoids,** as they are sometimes called, are formed in the cells of the same filament carrying the oosphere, or in a separate filament. In other words, Oedogonium is either monoecious or dioecious. The cells that produce antherozoids are usually narrow and smaller than the vegetative cells of the filament. In the dioecious species, the male filament contains a large number of these small cells or antheridia in series interrupted here and there by vegetative cells. Generally these filaments are slightly narrower than the vegetative and female filaments. In each antheridial cell two antherozoids are formed. Antheridia are formed by cell division of the ordinary vegetative cells, and the first dividing wall is always near the apex of the cell, in the case of monoecious species. In an antheridium the two antherozoids that are formed lie one above the other in some species, as the division of the protoplast is transverse while in others in which they are formed by a vertical division of the protoplast, they will remain side by side.

The antherozoids also escape, like the zoospores with a vesicle of hyaline membrane, swim about for some time and then they penetrate an oogonium through an aperture in the cell wall existing near the anterior end of the oosphere. After fertilisation the oosphere changes into an oospore in which a thick firm wall is soon formed. Ordinarily these bodies germinate only after a definite period of rest. They do not germinate and grow into plants immediately, just as zoospores do.

In some species of *Oedogonium* what are called "**dwarf male plants**" occur near the oogonia or on them. In the cells of these dwarf males antherozoids are formed and they get into oogonium and fertilise the oosphere. These dwarf male filaments develop from spores called **Androspores** which are intermediate in size, between zoospores and antherozoids. The androspore swims about and then settles down at or near the oogonium by its colourless ciliated anterior end and then grows into the dwarf male plant. The androspores are formed in short cells of the filaments either singly, or in chains.

SIPHONALES.

Vaucheria.—A very common genus, a few species are marine, and the rest are found in fresh and brackish water or in damp soil as a green felt. It is branched and **Coenocytic.** (Fig. 265). The reserve food here is oil and not starch. Asexual reproduction is by single large **multiflagellate zoospores** which are produced at the tip of the branches, the latter being separated into cells for this purpose.

Reproduction.—The **sexual** reproduction is very interesting and advanced in this genus. Not only is *Vaucheria* heterogamous,

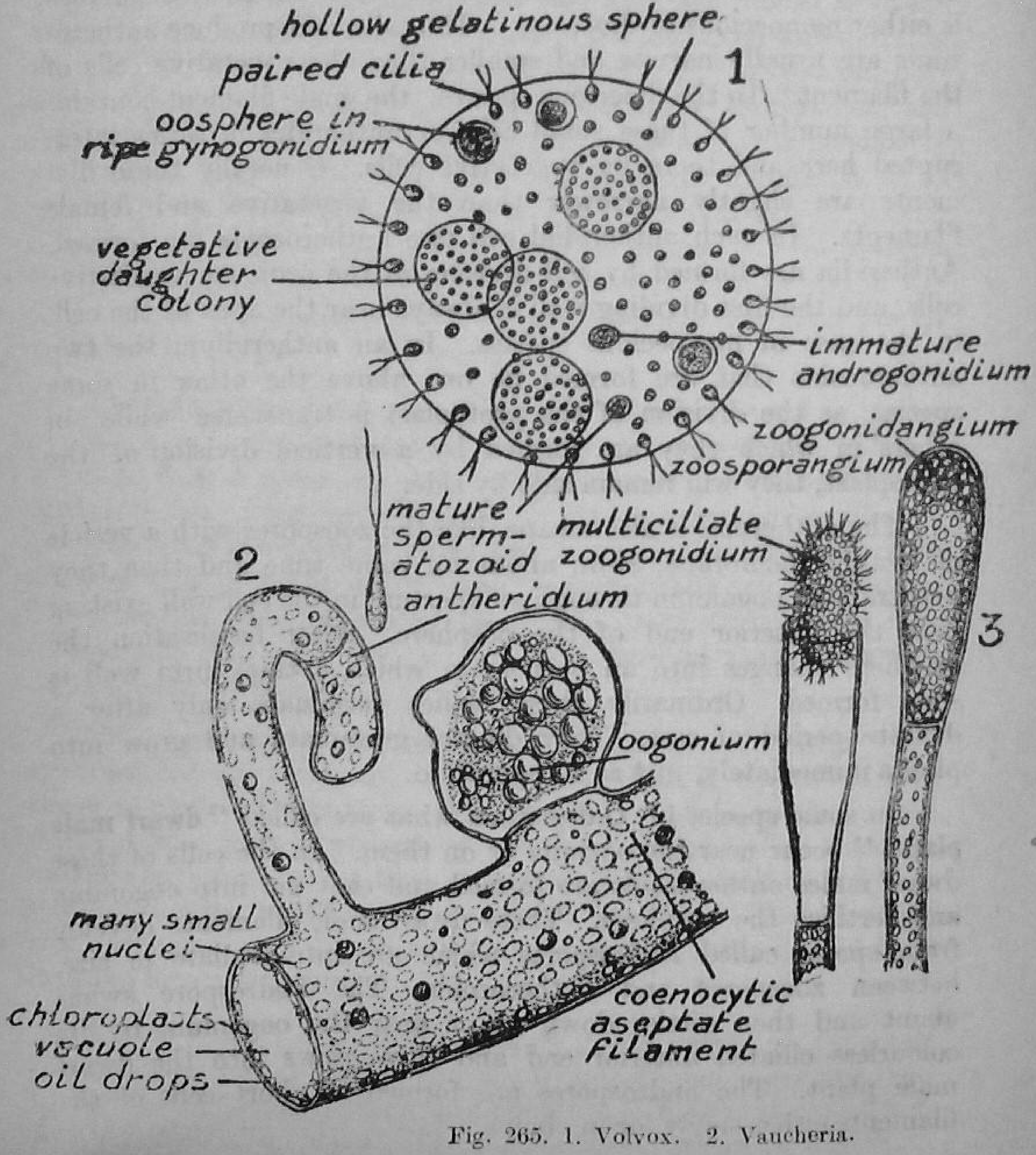


Fig. 265. 1. Volvox. 2. Vaucheria.

but it produces special sex organs which are not transformed vegetative cells, but are specifically for gamete production from the beginning. All of the fresh water species are homothallic; two or three of the marine species are heterothallic. The sex organs are very well developed—the *antheridia* or the male apparatus being at the ends of short lateral branches. The common fresh water forms have a hook-shaped antheridium opening by a terminal pore. The antheridium is multinucleate and densely cytoplasmic. A transverse wall separates it from the rest of the plant. The contents of the antheridium becomes divided into a number of uninucleate fragments each of which is metamorphosed into a biflagellate antherozoid. The *oogonium* begins to develop a little later than the antheridium and on the main thread close to the base of the antheridium. The cytoplasm here collects into the oogonium which has by this time become bulged out. This is also *coenocytic* like the antheridium and gets separated from the rest of the plant by a transverse wall. At the time of fertilisation the oogonium contains only a single nucleate egg. Antherozoids enter an oogonium through an apical pore produced by gelatinization of the oogonial wall. Several of them may enter but only one fertilizes. The zygote develops a very thick wall and enters upon a resting period of several months before it germinates.

Vaucheria has offered itself as a splendid material for experiments. By varying the character of the medium, the nature of the nutrition, light, etc., there may be produced at will sterile plants, zoospore producing plants or gamete producing plants. From experiments conducted on plants, like *Vaucheria* it is found that among the lower plants there exists a great ability to respond promptly to varying conditions.

Caulerpa, is entirely marine with about 60 species. The form is a one-celled thallus with a rhizome-like portion bearing root-like appendages on its lower face and erect shoot-like appendages on its upper face. The resemblance to a higher plant is very great here—the lower part like a creeping rhizome and the upper branches like " leafy-shoots " very much like mosses or lycopods. Beautiful specimens are obtained at Pamban and Rameswaram in the Indian Ocean.

Asexual reproduction by fragmentation of the thallus is very common. Biflagellate zooids are also formed, either in the rhizome or foliar shoots.

Sexual reproduction is isogamous or anisogamous (gametes of unequal size).

CHAROPHYCEAE OR STONEWORTS

Nitella.—Species of *Nitella* and those of the allied more common genus *Chara* occur mostly in fresh water in ponds, streams, wells, paddy fields, etc., very often in gregarious fashion. They require a sandy or muddy substratum in which the anchoring *rhizoids* can find a suitable foothold. Nitella generally occurs in deeper waters than *Chara.*

The thallus is made up of elongated internodes, separated by the nodes. At each node, there are branches which are arranged in whorls; the longer branches repeat the structure of the main thallus while the short ones are called leaves for practical purposes. In fact, though the form looks like a higher plant, there is no comparison with it in that there are no true leaves, branches, etc. *Nitella* has no sheathing cells over the internode and as such is easily distinguished from *Chara* which has a false cortex formed of these cells. The growth of the plant is by means of an **apical cell.** The attachment is effected by means of colourless branched rhizoids springing from the nodes at the base of the axes.

Each cell is uninucleate but as a result of fragmentation each internodal cell is provided with a number of nuclei which lie embedded in an inner and actively moving layer of protoplasm. The chloroplasts are large, numerous and round. *Nitella* and *Chara* are excellent laboratory material for the study of movement of protoplasm.

Reproduction.—**Asexual** reproduction by means of swarm spores or others is wanting in **Nitella** and **Chara.**

Sexual reproduction is, on the other hand, very much advanced. The female organs **oogonia** are ovate, large and visible to the naked eye. They are inserted on the nodes of the lateral axes in their younger parts. The male organs, the **antheridia,** are also inserted on the nodes close to the oogonia. Most of the species are monoecious. The fertilized egg-cell develops into an **oospore.** (Fig. 266).

The antheridium develops from a mother cell that first becomes divided into eight cells, each octant by two tangential external tabular cells of the wall—the "**shield**" cells, the cavities of which are incompletely partitioned by septa extending in from the cell wall; the eight middle cells form the **manubria** and become elongated; the eight innermost cells assume a spherical form as the primary **head cells.** Owing to the rapid surface growth of the eight shield cells, a cavity is formed within the male organ into which the manubria bearing the head cells project. The latter form

3—6 secondary head cells and each of these give in its turn 3—5 long unbranched spermatogenous filaments. These are composed

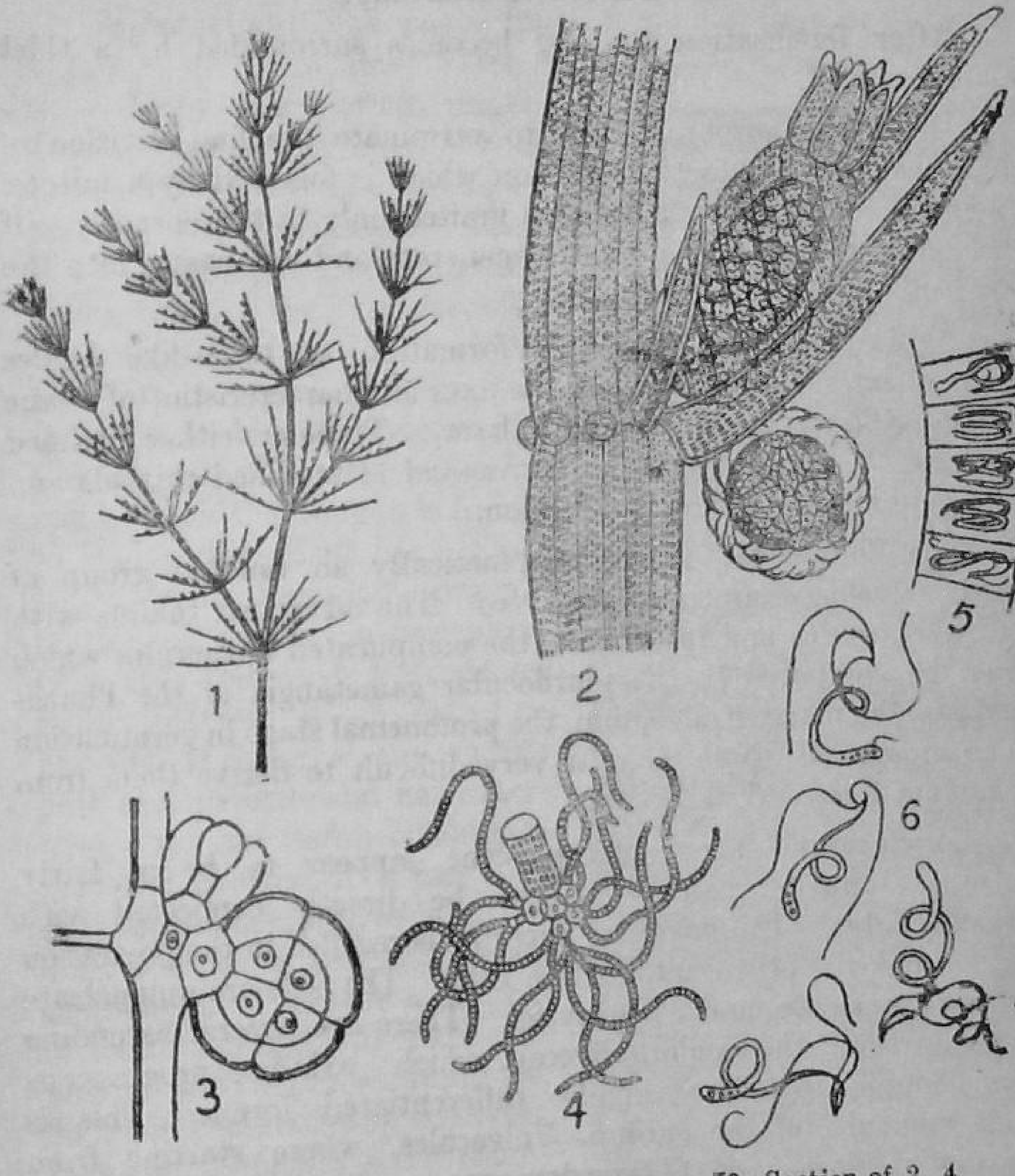


Fig. 266. Chara; 1. Plant; 2. Sexual organs; 3. Section of 2, 4, and 5. Sperm filaments; 6. Sperms.

of disc-shaped cells from each of which a spirally wound spermatozoid with two cilia is liberated. A ripe antheridium when crushed and mounted in a drop of water will show all the details—the shield cells, the manubrium, the head, the sub-head and the cells of the sperm filaments.

The female organ consists of an **oogonium** which contains a single egg-cell with numerous oil drops and starch grains. In the beginning, the oogonium projects freely, but later cells from

the base surround the oogonium, wound in a spiral fashion and form a crown of ten cells arranged in whorls of five in two tiers. *Nitella* is thus distinguished from *Chara* by the crown of ten cells while in *Chara* the crown is of five cells only.

After fertilisation the egg becomes surrounded by a thick colourless wall.

When the oospore begins to germinate the first division of the nucleus is a reduction division which is followed by a mitotic division. So the diploid stage is limited only to the oospore. Of the four resulting nuclei, three degenerate and one passes into the germ tube.

As in most aquatics, the formation of tuber-like bodies (bulbils) on the lower part of the axes is characteristic of some species of **Characeae** (Nitella and Chara). These are either modified nodes of the shoot portion or correspond to modified rhizoids and they help in vegetative reproduction.

The **Characeae** form phytogenetically an isolated group of highly developed green thallophytes. The advanced thallus with its leaves, nodes and internodes, the complicated antheridia which could be compared to the plurilocular gametangia of the **Phaeophyceae**, the massive oogonium, the **protonemal** stage in germination as in mosses, all these make it very difficult to derive them from oogamous Green Algae.

Conclusions.—The chlorophyceae appear to be a fairly natural group of plants that can be directly connected with the flagellates. The flagellate ancestry is recalled in the possession of their naked motile, reproductive cells. The cells are uninucleate or multinucleate and coenocytic. There are several ascending series within the chlorophyceae which exhibit progressions from simple to more highly differentiated forms. This is best studied in the group **Volvocales,** where starting from unicellular forms the **Chlamydomonas,** multicellular colonies as in **Pandorina, Eudorina** and **Pleodorina** with equivalent unconnected cells that can serve all for vegetative life and for reproduction, lead on to multicellular individuals with pronounced division of labour between their cells. As regards sexual reproduction, progressive differentiation can also be followed from isogamy to heterogamy and then to distinct oogamy.

CHAPTER XXIX

FUNGI

Introduction: The name fungi (Singular fungus) is given to a group of organisms which have certain definite characteristics. They are placed under Thallophyta as they have only a thallophytic body like the algae and the blue green algae. That means the fungus has no distinct stem, root, leaf or vascular tissues, characteristic of either the fern or seed plant. The fungus resembles the bacteria in the absence of green pigments and as such the fungus is forced to lead a dependent life. When it feeds on decaying organic matter, it is called a **saprophyte** (Fig. 267) and when it feeds on living matter it is called a **parasite.** If the organism can live only as a parasite and not otherwise, it is termed **obligate parasite;** likewise if it can live only as as a saprophyte and not otherwise it is termed **obligate saprophyte.** There are a number of parasitic fungi which are capable of thriving as saprophytes. Such are **Facultative saprophytes.** Likewise there are some **saprophytic fungi** which are capable of thriving as parasites. Such are **facultative parasites.**

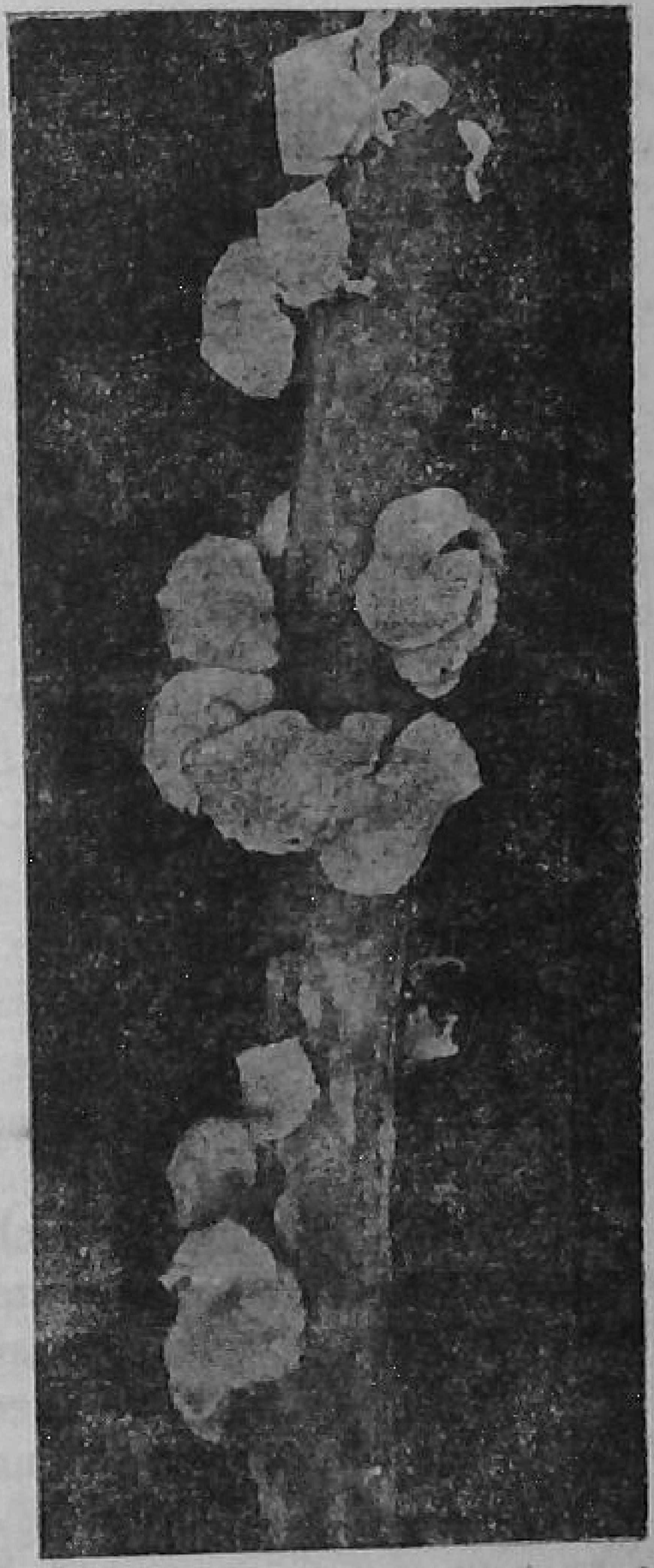


Fig. 267. A Saprophtic Fungus growing on a dead piece of wood.

While the fungi resemble bacteria in their mode of nutrition, they resemble the algae in their plant body and method of reproduction. When a few types are studied these will be understood.

Fungi vary in colour and size. The yeast fungus is a single cell. There are larger forms like the mushroom and the Bracket fungi. Except in the latter case, all fungi are generally soft. The body of the fungus consists of branched threads termed the *Mycelium*,

while an individual thread is called a **hypha** (plural—hyphae). The hypha when examined under the microscope is made out to be a tubular structure. The cell wall material is called a fungus cellulose which is different from the ordinary cellulose. It is more like chitin. The hyphae may be septate or nonseptate. Where it is nonseptate and multinucleate it is termed a **coenocyte.** Fungi have uni or bi-nucleate cells. The cells contain protoplasm. Vacuoles are present. Starch is absent while protein, fats (oil globules) and carbohydrates in the form of glycogen are present. All fungi require plenty of moisture for growth. Exclusive of the lichens the fungi or Eumycetae include some 75,000 species distributed among 2,850 genera.

REPRODUCTION IN FUNGI

Sexual reproduction.—Gametes are produced by the fungus. The male and female gametes fuse to form a single celled zygote which, usually after some resting period, germinates to form the mycelium. The gametes are of different kinds as noted below :

(1) The male and female are both of free swimming types. They swim about and fuse to form the zygote, which after rest develops into the fungus again.

(2) The male gamete is an active spermatozoid while the female gamete is a passive one. Fertilization is effected by the active movement of spermatozoid.

(3) The male and female gametes are represented by two specialized cells called gametangia and these may be uninucleate or multi-nucleate. The gametangia may be differentiated in their form and function in which case the male is termed **antheridium** and the female **oogonium.** These may be developed on adjacent hyphae to facilitate fusion. In some cases, the antheridium may get detached and carried by external agencies towards the female. Such an antheridium is termed a **spermatium.**

(4) In higher fungi, two strains (plus and minus) of hyphae fuse to give rise to sporophytic generation. Reduction division follows and haploid spores are produced. When these spores are produced **endogenously** in the mother cell **ascus** they are termed **ascospores ;** if they are produced **exogenously in basidium,** they are termed **basidiospores.**

Asexual reproduction.—The asexual method of reproduction is by accessory spores. The different types of accessory spores are described below :—

(1) In many of the lower fungi, **zoospores** which are motile spores provided with cilia are developed in spherical or tubular

sporangia called **zoosporangia.** This type of reproduction is common in aquatic forms.

(2) In connection with the change from the aquatic to sub-aerial conditions, changes in the spore character took place—the contents of the sporangium came to be shed as *walled non-motile* spores or the sporangium itself came to be let free without division of its contents and formation of spores. Such a structure borne externally on its parent hypha is termed a **conidium.** In other words the sporangium thus becomes a **conidium,** a spore borne externally on its parent hypha and not enclosed in any kind of sporangium. The conidium is the characteristic unit of accessory multiplication in many fungi. By means of the conidia the fungi are enabled to increase and disseminate rapidly. In this respect they are comparable with gemmae of Marchantia. The conidium generally germinates by the protrusion of one or more germ tubes. Where the fungus has access to water, the conidium may give rise to zoospores. Conidia are usually developed, either singly or in groups, upon stalks known as **conidiophores.** Conidiophores show an almost endless variety of form and arrangement. Conidiophores may be freely exposed to the air or they may be produced inside a special flask shaped structure termed the **pycnidium.**

(3) There is another type of spore called *chlamydospore*. It is also a propagative cell but rather rare. The chlamydospore is thick walled and is a resting spore with the least moisture in its body. The chlamydospores are found either singly or in chains, in ordinary vegetative hyphae or in special branches.

(4) In some fungi the vegetate hyphae may divide into short segments which separate and function as propagative spores. These are termed as **oidia.**

(5) Many conidia, as well as other thin walled spores, are able to **bud,** that is they give rise to lateral outgrowths which are nipped off as new cells. Vegetative cells may also increase by **budding** and this is very characteristic of the yeast fungus.

Dissemination of Fungi.—In the case of the higher plants it was noted that there are different means by which they spread. Some occupy new areas with the help of their seeds, others by means of such specially modified stems like the rhizome, bulb, tuber, corm, etc. In the case of the fungi, spread by means of the mycelium and spores are very common. In cases where it is by mycelium the mycelium is carried with the substratum on which it is growing, *e.g.*, a rotting fruit or piece of bread. This involves

fairly large pieces of the substance carrying mycelia, *e.g.*, potato blight.

By far the most common and efficient method of dissemination is by means of wind borne spores. The different kinds of spores, the conidiospores, oidia, ascospores and basidiospores are rapidly carried over long distances by the agency of wind. The fungus produces millions and millions of spores. The spores have further devices to make them effectively spread. These spores are disseminated through various agencies such as wind, water, birds and man out of which wind borne spores are the most common.

Dissemination by wind.—The spores are generally microscopic in size and light in weight. They can freely float in air. In addition, the spores have other devices, some have tiny spires, some are sticky so that they adhere firmly to the leaves, or stems on which they fall and germinate. There are some with thread like tails which assist them in floating in the air and in fastening them to their hosts on which they fall.

Dissemination by water.—The zoospore method of reproduction has already been mentioned. This is very common in the fungi (*Pythium*, *Phytophthora*, *Cystopus*, etc.), Irrigation water, and flood water may be responsible for the spread of many pathogenic types. Sometimes *sclerotia* are carried by stream water from place to place.

Dissemination by birds, wild and domestic animals and insects.—These carry mycelia or spores and thus disseminate them.

Dissemination by man.—Man is a very potent agent in the dissemination of fungi. In all concerns connected with exports and imports there is the movement of grains, fresh and canned food, fruits, vegetables, etc., and there is every chance of fungi being carried from place to place if strict precautionary measures are not taken to ensure their freedom from fungi every time an article is moved.

Apart from the danger of fungus being carried by ships, trains, planes, etc., local distribution of a fungus may take place, through improper handling of the soil, manure, litter, etc., or, in other words, manure or litter may contain a fungus and this, if not detected, may prove a source of danger of infection when carried to another place.

Plant material such as seeds, tubers, rhizome, cuttings and grafts help in the dissemination of different fungi from place to

place if they happen to be the carriers of the fungi on their bodies. Hence it is that great precautions are taken to see that all plant materials which are used for propagation are fungus free. There is therefore the practice in modern times of fumigating articles before they are sent from one country to another and unless a certificate of fumigation is attached no article is accepted when it arrives in. There are plant protection officers appointed for doing this very important piece of work. By this international cooperation diseases are checked.

The fungi are thus disseminated in various ways and some of these will be discussed in a later section when we deal with diseases and their control.

Importance of Fungi.—A good number of fungi render havoc by causing diseases to crops and animals—some saprophytes damage food, butter, timber, leather, etc., and some parasites cause diseases to crops. There are also a few which render valuable service. Yeast fungi are important in brewery, bread making and supplying yeast food rich in B Vitamin. Ergot and Penicillin, the two important therapeutic products are from fungi. There are mushrooms which are edible.

Fungi are important to us in many ways. Much knowledge has been gathered about them and this branch of general botany is termed **Mycology** which deals with life history and structure of fungi. A study of the diseases of plants is termed plant pathology.

The fungi are classified as follows :—

FUNGI

- Vegetative mycelium usually aseptate
  - **Phycomycetes**
- Vegetative mycelium septate
  - Characteristic spores endogenous
    - Ascospores
      - **Ascomycetes**
  - Characteristic spores exogenous
    - Basidiospore
      - **Basidiomycetes**
  - Ascospores and basidiospores
    - Lacking
      - **Fungi Imperfecti**

Phycomycetes ..

- (1) Mycelium absent or rudimentary :—
  - **Archimycetes :**—
    - (*a*) Chytridiales
    - (*b*) Ancylistales
    - (*c*) Protomycetales
- **(2) Mycelium well developed**

FUNGI.—*contd.*

Sexual reproduction Oogamous accessory spores often motile

Oomycetes

(*a*) Monoblepharidales
(*b*) Saprolegniales
(*c*) **Pernosporales**—
- Pythiaceae .. Pythium, Phytophthora
- Albuginaceae .. Cystopus
- Pernosporaceae .. Plasmophora, Sclerospora

Sexual reproduction isogamous, anisogamous or by aplanogametes

Zygomycetes

(*a*) **Mucorales**
(*b*) Entomophthorales

Ascomycetes : —(1) **Ascocarp is present either with no definite opening or shield shaped or with asci irregularly arranged**

Plectomycetes .. (*a*) Plectascales, (*b*) Erisiphales, (*c*) Exoascales.

(2) Ascocarp wide open when ripe, **asci in parallel series Discomycetes**

Discomycetes :— .. (*a*) Pezizales, (*b*) Helvellales, (*c*) Tuberales, (*d*) Phacidales, (*e*) Hysteriales

(3) Ascocarp **flask-shaped opening by an ostiole when ripe, asci in parallel series ; Pyrenomycetes.**

(*a*) Hypocreales
(*b*) Dothideales
(*c*) Sphaeriales
(*d*) Laboulbeniales

Basidiomycetes
- (1) Number of basidiospores indefinite **Hemibasidiomycetes :—**
- (2) Number of basidiospores usually four, **Ustilaginnales**

Basidium septate

Protobasidiomycetes

(*a*) Uredinales
(*b*) Auriculariales
(*c*) Tremellales

Basidium Continuous

Autobasidiomycetes

(*a*) Hymenomycetales
(*b*) Gasteromycetales.

Fungi Imperfecti
- (1) Conidiophores not grouped in Pycnidia
  - Stromata not present — **Hyphomycetales**
  - Stromata present — **Melancoliales**
- (2) Conidiophores grouped in pycnidia **Sphaeropsidales.**

Phycomycetes.—These include about 1,000 species. The members of this group are characterized by a nonseptate mycelium which becomes septate before the formation of a reproductive body and algae like reproductive habits. Many are aquatic in habit and some aerial.

Phycomycetes :—
- Archimycetes.
- Oomycetes.
- Zygomycetes.

Archimycetes.—Lowest group-saprophytic and no well developed mycelium.

Oomycetes.—Aquatic or aerial. In most of them there is a well developed mycelium. The plant leads either a saprophytic or parasitic life—Asexual reproduction is by means of sporangia which usually produce motile zoospores which are biciliate. Some germinate conidially. Chlamydospore formation is also prevalent.

Sexual method of reproduction is by formation of oospores as a result of the fusion of male and female gametes. In one group motile male gametes are formed.

Oomycetes :
- *Monoblepharidales* .. Motile sperm.
- *Saprolegniales* .. Aquatic.
- *Pernosporales*
  - Pythiaceae
    - Pythium,
    - Phyto--phthora
  - Albuginacea--Cystopus.
  - Pernosporaceae—Plasmophora. Sclerospora.

Zygomycetes.—Are more aerial in habit, either saprophytes or parasites. Some are parasitic on insects. Mycelium is well developed and non-septate.

Asexual method—sporangia—nonmotile spore—conidia, chlamydospores.

Sexual conjugation of 2 similar gametangia-zygospore.

Zygomycetes—Mucorales—*Rhizopus.*
Entomophthorales—parasitic on insects. Only conidia are formed. Sporangia are not formed.
Empusa musci-parasitic on flies.

OOMYCETES—PYTHIACEAE.

Pythium aphanidermatum—Is present in the soil and is responsible for the disease known as "Damping off" of seedlings. This disease is prevalent in South India. Seedlings are attacked at the ground level, where as a result of the attack by the fungus, the tissues collapse and the plants are killed. The fungus appears when the seedlings are overcrowded and there is excessive moisture. In the laboratory, the fungus can be studied by raising mustard seedlings in a crowded form. Tobacco, chillies, tomato are attacked in the nurseries by this fungus. It also attacks roots of papaya and causes "Foot rot of Papaya."

Morphology.—The hyphae are colourless, filamentous and non-septate. Partition walls form just before the reproductive bodies are formed.

REPRODUCTION :—Asexual.—Terminal or intercalary lobed sporangia are formed (see fig. 268). These are formed very easily when there is plenty of water. One of the lobes develops into a tube which after growing for some time develops into a vesicle, where after a short time it gets divided into a number of bean shaped tiny bodies each of which is a biciliate zoospore. The sporangium germinates under conditions where there is low temperature, plenty of oxygen and enough water. The zoospores float and move in water for 10–30 minutes ; the cilia are lost when they become rounded. At this stage the zoospore puts out a tubular outgrowth which is called the ' germ tube'. This grows and develops into the mycelia. This method of reproduction is for the rapid multiplication of the organism. This is known as the *indirect method.* One can easily imagine from the number of sporangia formed on the fungus and the large number of zoospores produced in each sporangium, how rapidly the fungus is capable of multiplication.

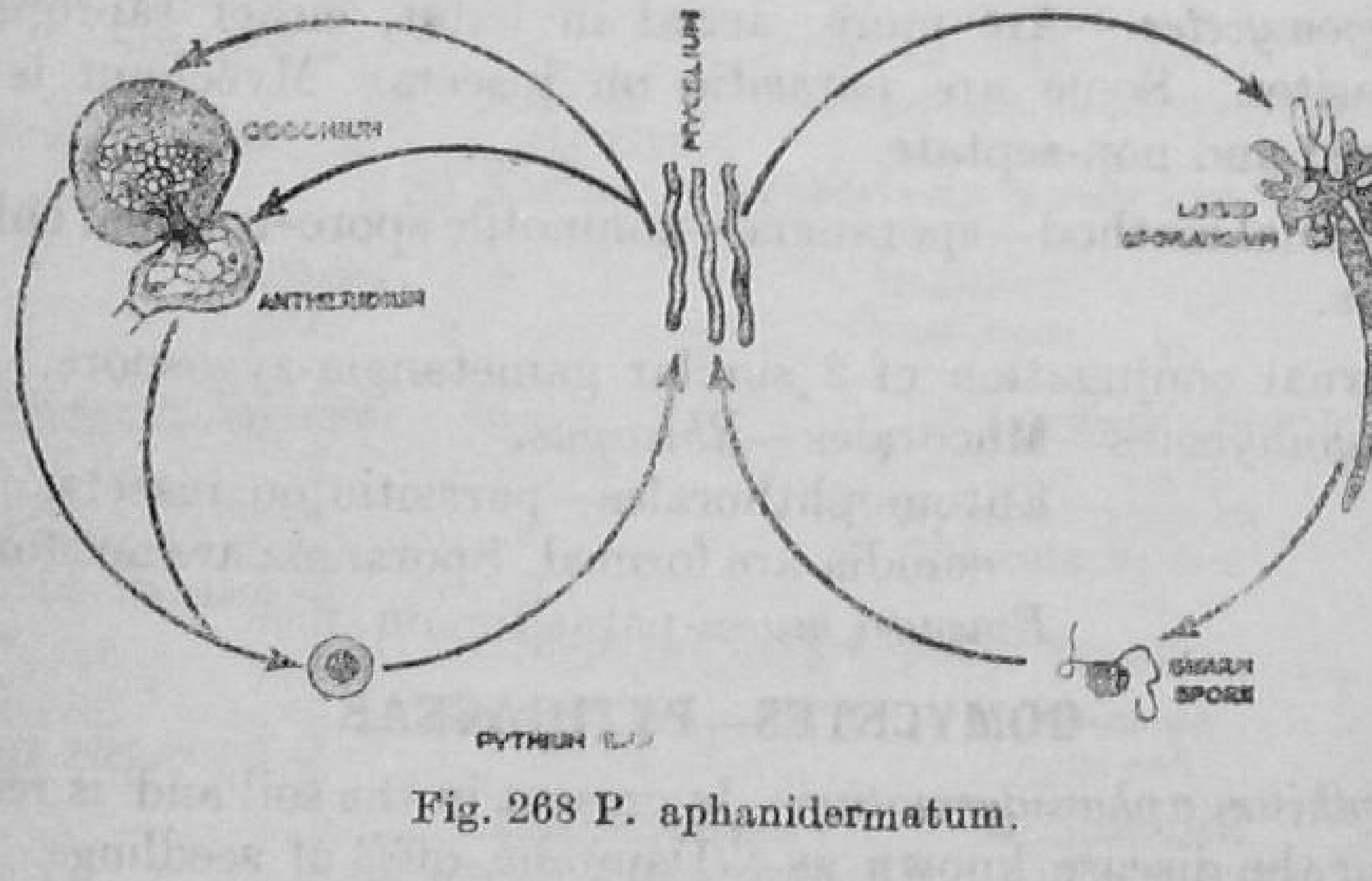


Fig. 268 P. aphanidermatum.

The *direct* method of germination takes place when the temperature is higher and there is not enough oxygen. The mycelium develops directly from one of the lobes of the sporangium.

Sexual method.—When conditions become unfavourable this method is generally resorted to.

From one of the branches a spherical body is formed at the tip which represents the female organ, the **oogonium**. The oogo-

nium is separated from the rest of the hyphae by a partition wall. From the same hyphae or another hyphae an **antheridium** is deve-

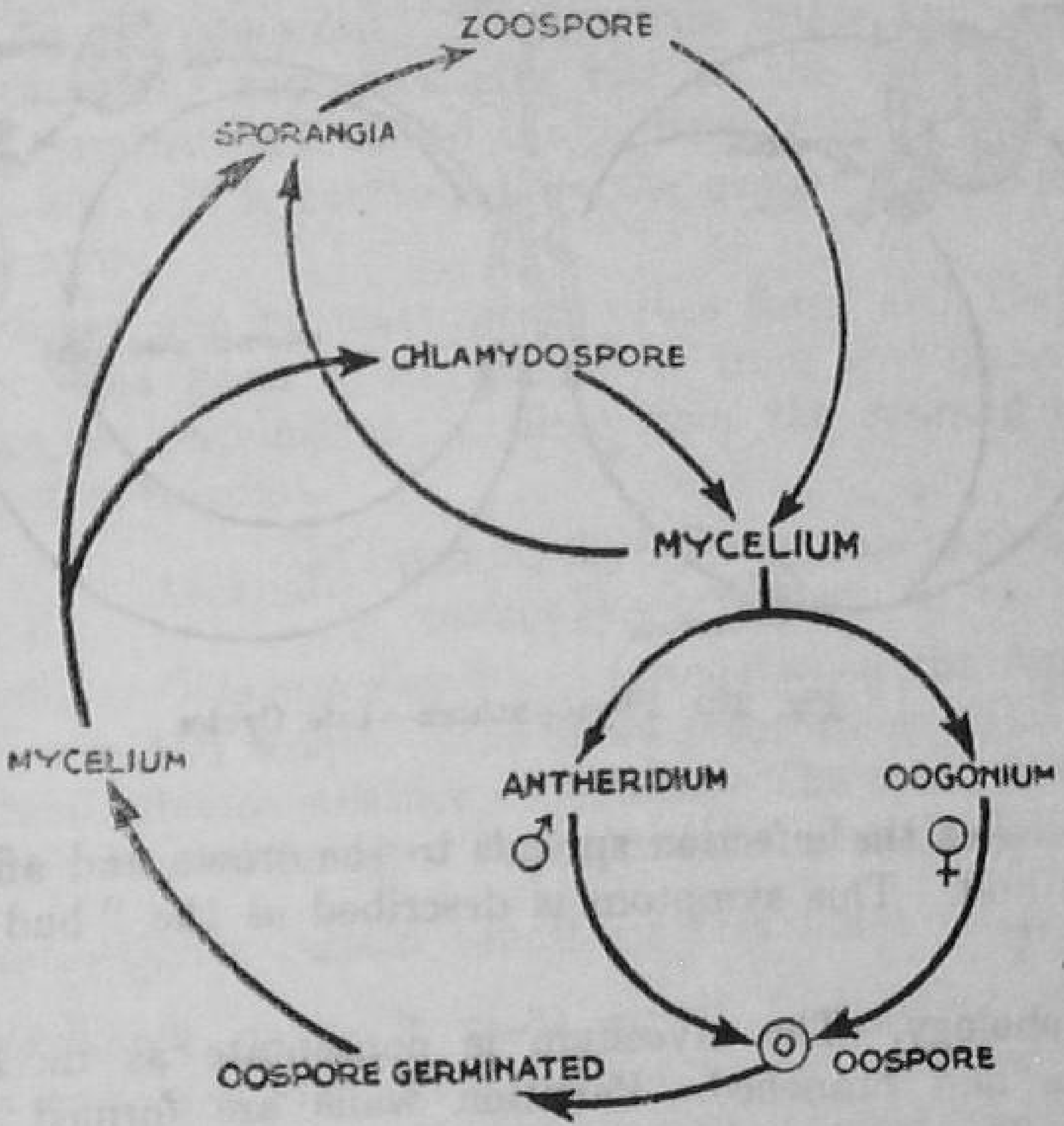


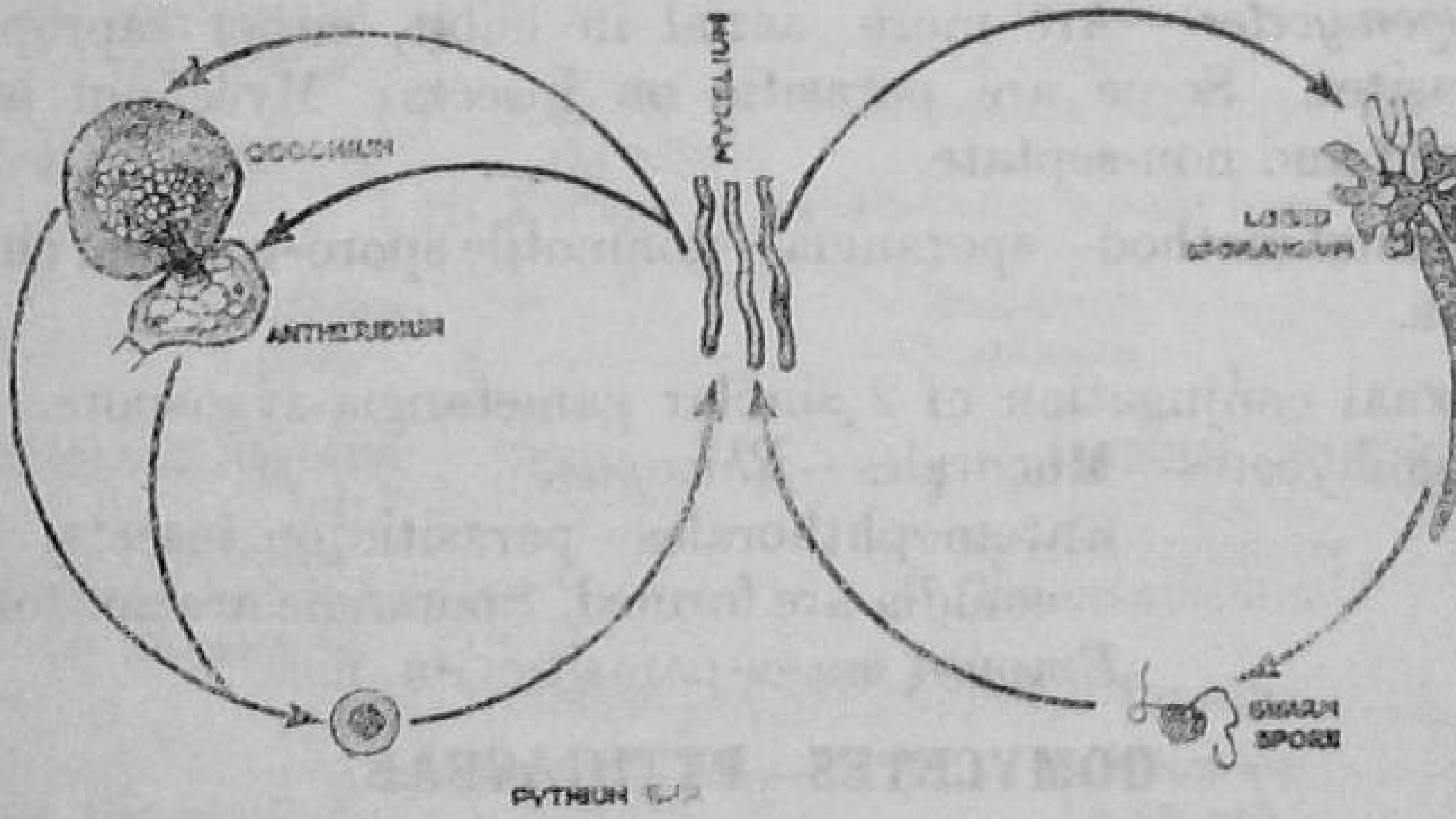
Fig. 269–Phytophthora–Life Cycle.

loped, which attaches itself to the side of the oogonium. This is termed **perigynous** antheridium. The antheridium pierces the wall of the oogonium and its contents fuse with the **oosphere** or the egg and in this way sexual fusion or fertilisation is effected (*see* Fig. 269). The fertilized oosphere now produces a thick wall. The "**oospore**" as it is now termed is slightly yellow in colour and being thick walled viable for a long time. When favourable conditions set in, the oospore germinates and develops into a mycelium.

Phytophthora arecae (**Pythiacece**).—This is responsible for the disease of arecanut called fruit rot or "Mahali or the Kole-roga." This disease is seen in Myscre and West Coast during the South-west monsoon periods. The disease is characterised by the rotting of the nuts. Consequently the nuts drop down from the bunch. At times when the attack is severe all bunches may drop down and bare stalks left. When the affected nut is cut open,

Morphology.—The hyphae are colourless, filamentous and non-septate. Partition walls form just before the reproductive bodies are formed.

REPRODUCTION :—Asexual.—Terminal or intercalary lobed sporangia are formed (see fig. 268). These are formed very easily when there is plenty of water. One of the lobes develops into a tube which after growing for some time develops into a vesicle, where after a short time it gets divided into a number of bean shaped tiny bodies each of which is a biciliate zoospore. The sporangium germinates under conditions where there is low temperature, plenty of oxygen and enough water. The zoospores float and move in water for 10–30 minutes ; the cilia are lost when they become rounded. At this stage the zoospore puts out a tubular outgrowth which is called the ' germ tube'. This grows and develops into the mycelia. This method of reproduction is for the rapid multiplication of the organism. This is known as the *indirect method.* One can easily imagine from the number of sporangia formed on the fungus and the large number of zoospores produced in each sporangium, how rapidly the fungus is capable of multiplication.



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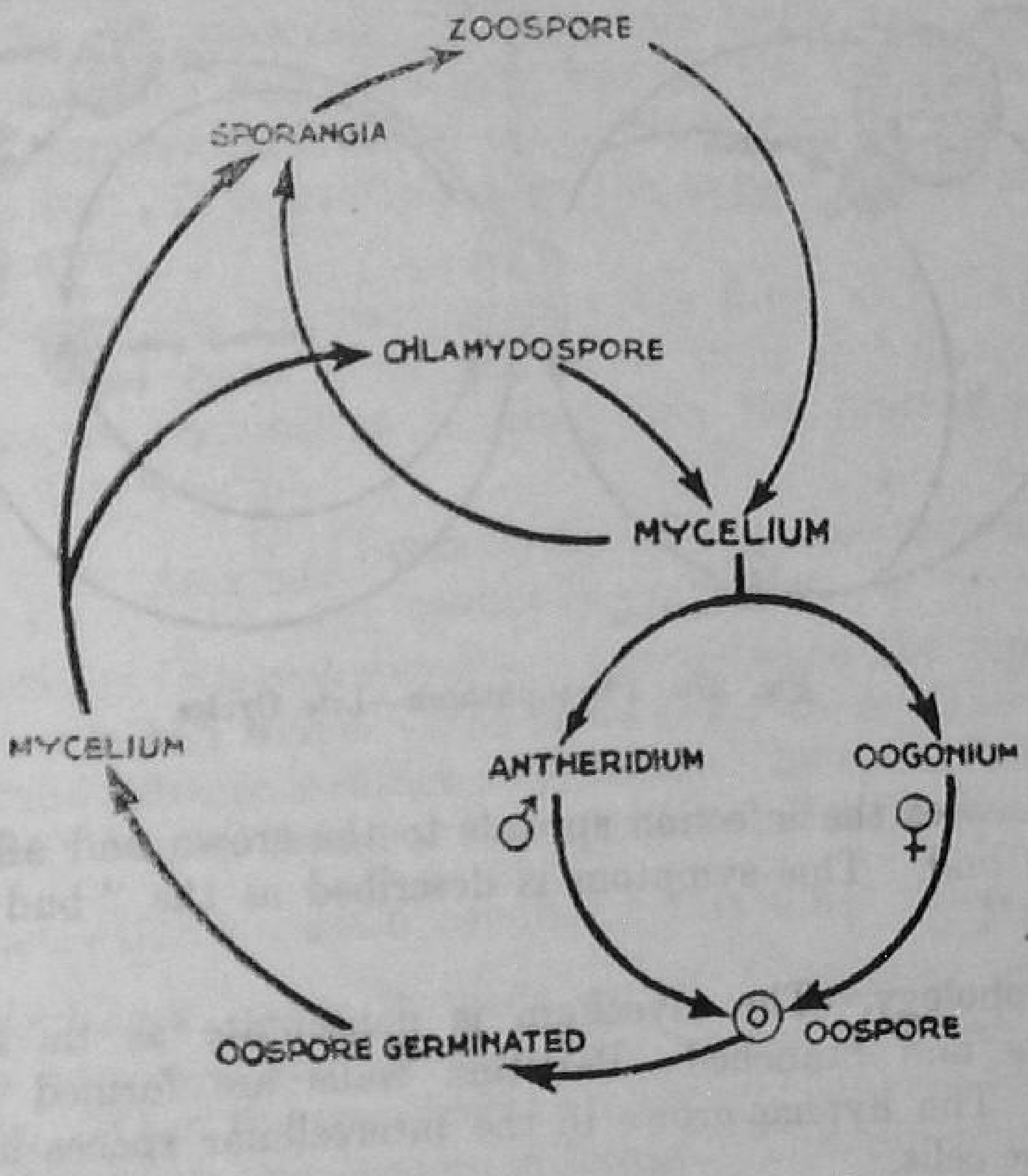

Fig. 269–Phytophthora–Life Cycle.

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the fungus is made out as a white fuzzy mass. The mycelium may be seen also on the surface of the fallen nut as a white growth.

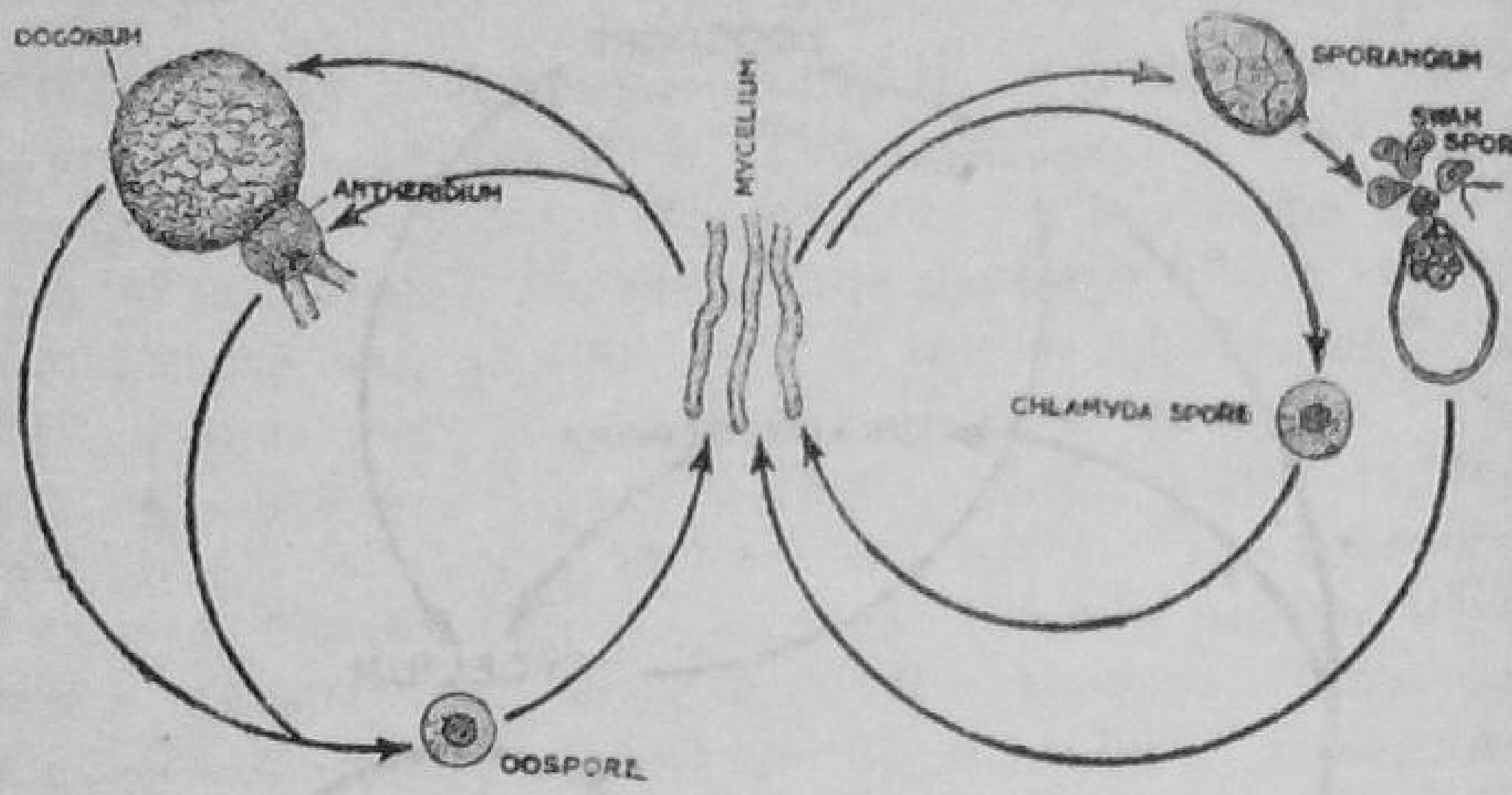


Fig. 270. Phytophthora—Life Cycles.

In some cases the infection spreads to the crown and affects the terminal bud. This symptom is described as the "bud rot" of arecanut".

Morphology.—The mycelium is nonseptate as in *Pythium*, colourless and branched. Partition walls are formed in older hyphae. The hyphae grows in the intercellular spaces and then enters the cells.

REPRODUCTION :—Asexual.—In the early stages asexual method of reproduction takes place. The sporangium is not lobed as in *Pythium.* It is pear shaped, colourless, one celled and filled with granular protoplasm. (see fig. 270). There is found a small projection at the free end of the sporangium termed the 'papilla' which is characteristic of the genus *Phytophthora* and absent in *Pythium.* Sometimes the sporangia are cucumber shaped and thin walled. These are borne on their stalks called **sporangiophore.** In the formation of sporangia, sympodial method is seen. Sometimes the sporangia are formed intercalary.

Germination.—When the sporangium is placed in water at low temperature, it starts germinating. It exhibits variations. Sometimes a thin sac like structure or vesicle is formed at the papillar end and the protoplasm moves into this where it divides into bits which move about as in *Pythium* and are finally liberated by the rupturing of the wall. Each of these bits is a biciliate reniform zoospore. The cilia drop out, the zoospore becomes round, forms a germ tube and the mycelium.

Instead of forming a vesicle in the sporangium, the protoplasm undergoes modification into a number of bits. The sporangial wall finally bursts at the papilla and zoospores come out of the sporangium through the papillar opening. Sometimes all zoospores do not come out. They remain inside and germinate. In both cases the zoospores give rise to the mycelium. This method of germination is called the indirect or sporangial method of germination. It is controlled by the oxygen available, water and temperature.

Sometimes one or more germ tubes form and they begin to branch. The germ tubes can start from any place. I this case where the germination is direc from the sporangium it is called direct or conidial.

Asexual { Sporangially—Zoospores—mycelium
conidially—mycelium.

Sometimes *Chlamydospores* are formed when the fungus has to tide over a bad season. The spore being thick walled is able to withstand adverse weather conditions. The spore is spherical and yellow; formed terminal or intercalary. Papilla is absent.

Sexual.—Under certain conditions this takes place.

Phytophthora arecae is made up of 2 different strains of organism namely + and —. It cannot be distinguished—as male or female. When the two strains are brought into contact fertilization takes place and oospore is formed. This difference in the hyphae is termed **heterothallism.** Just because one is not able to distinguish the form as male or female, they are termed + and — and when they fail to contact, reproduction is only by sporangia or chlamydospore formation. The sexual organs are antheridium and oogonium as in *Pythium.* The antheridium is formed as a club shaped body from one hypha. From another hypha an oogonium is formed which comes into contact with the antheridium and the latter pierces into oogonium, swells up into a globular structure. This kind of an antheridium that forms a circle round the oogonium is called an *amphigynous antheridium.* As a result of fertilization a thick walled oospore is formed. *Phytophthora arecae* forms only amphigynous antheridia. *Pythium aphanidermatum.*—It was noticed that the antheridium was attached to a side (see fig. 268). In this case it is called a *paragynous antheridium.* When favourable conditions set in the *oospore* germinates into mycelium. The other economically important species of *Phytophthora* are (1) *P. palmivora* which causes bud rot of coconut, Palmyra leaf fall and fruit rot of orange; (2) *P. meadii*—leaf fall

of rubber, a serious disease in rubber areas like Malabar, Cochin and Travancore ; (3) *P. parasitica* var *nicotiana*—Black shank of tobacco.

ALBUGINACEAE

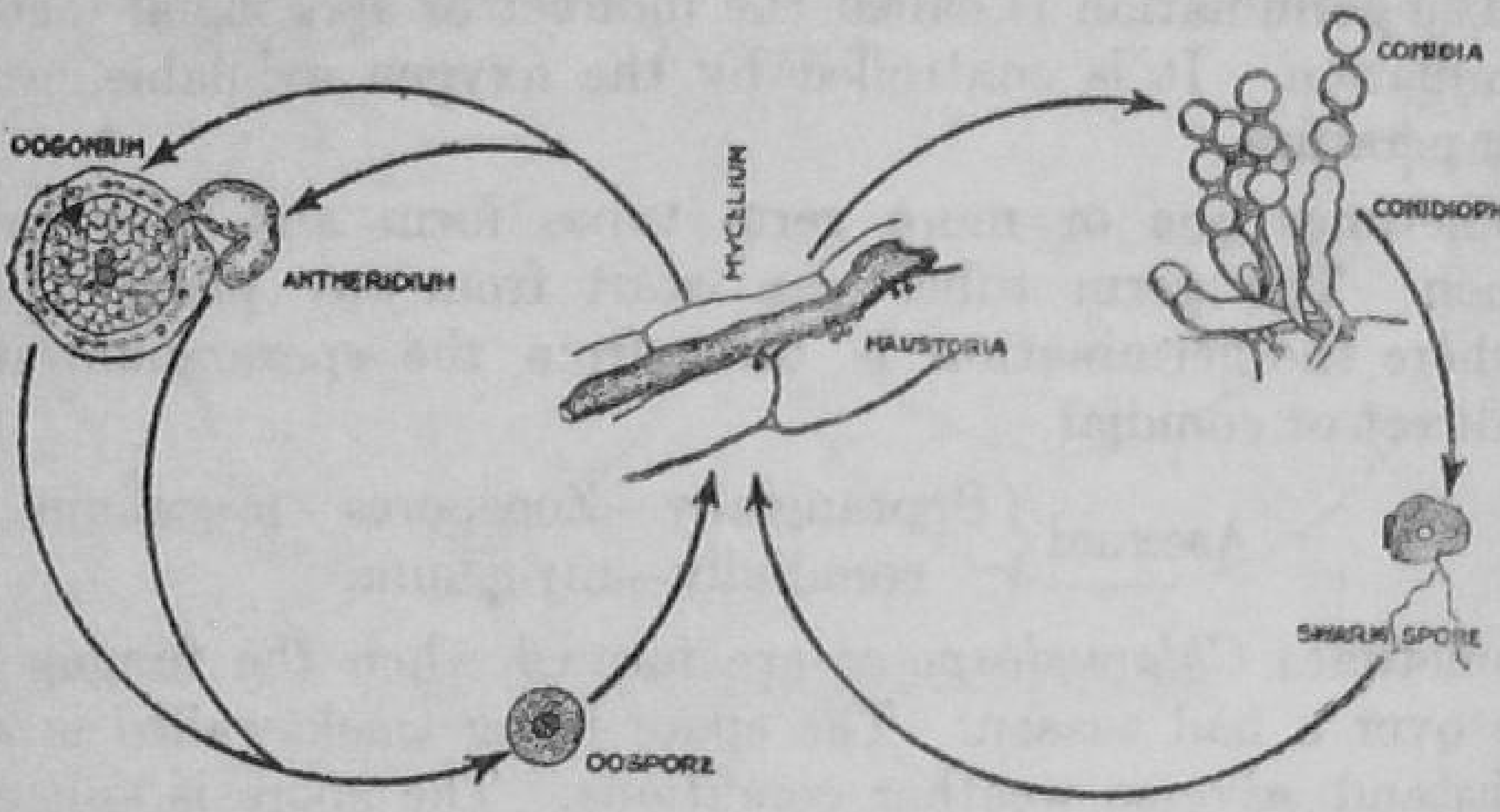


Fig. 271. Cystopus—Life Cycle.

Cystopus candidus (*Albugo candida*)—White Rust fungus (Albuginaceae)—Though it is called a rust, this plant has nothing to do with the true rusts. It is a parasite on a number of common wild and cultivated plants. Members of the Cruciferae such as cabbage, mustard and radish are attacked. It is also very commonly met with on *Merremea emarginata*, a very common Convolvulaceous weed in South India. Unlike *Pythium*, which is aquatic, white rust is aerial in its habit.

Morphology and reproduction.—Prominent swellings are to be noted on the upper and under surfaces of the leaves of the infected plant which are white. On account of these white pustules which show off the disease it is termed as white rust. The hyphae are intercelluar and send button shaped haustoria into the cells (see fig. 271). After some time asexual reproductive bodies are formed. There are club shaped bodies—the *sporangiophores*—arranged in one layer. The epidermis is pushed out when these elongate. From the tip of each sporangiphore a chain of sporangia is produced. (see fig. 271). In between the sporangia the wall becomes gelatinous and this disc of gelatinous substance is termed an isthumus. When the sporangia ripen, the isthmus dries up and helps in the separation of the sporangia from one another. The whole structure—a layer of sporangiophores with chains of sporangia—is called a

sorus. The topmost sporangium is usually thick walled as it has to push up the epidermis and rupture it with mechanical strength.

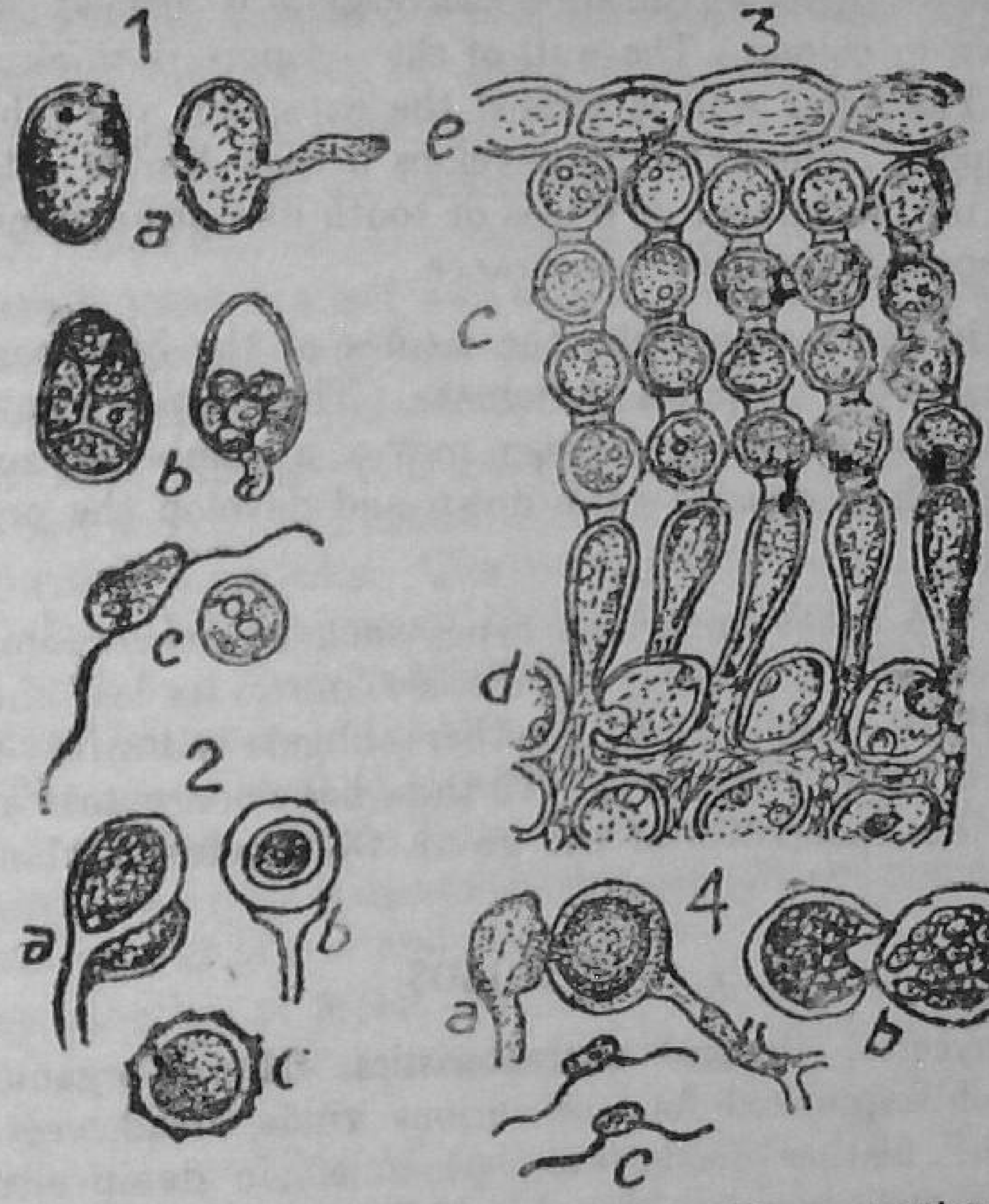


Fig. 272. Cystopus candidus. 1. a. conidia germinating; b. Zoospores inactive; c. Zoospore active; 2. A 8 B, Sexual organs and c. Oospore; 3. T. S. Leaf showing chains of sporangia and isthmus,; 4, a. Sex. organs; b, germinating Oospore again 8 c. Zoospores.

This usually does not function as a reproductive body. The others are thin walled and colourless. In wet situations the contents undergo division, the walls give way and 8 to 16 zoospores escape. These are also called swarm spores as they move about in water. The zoospore which is kidney shaped and biciliate, drops the cilia, becomes rounded, settles down, puts forth a germ tube and forms the hyphae. In this way the fungus very rapidly multiplies itself.

As a result of the attack of the fungus the habit of the plant changes as, for *e.g.* in *Merremia*, the attacked branches become erect from the normal prostrate condition.

Sexual Method.—Sexual reproduction takes place inside the tissue of the affected plant, *i.e.*, in the intercellular spaces of the host tissue. The oogonium is developed by one hyphae and

another develops the antheridium. Fertilization tube is formed by the antheridium and the antheridial contents transferred into the oosphere. After fertilization the oospore is formed which is dark brown in colour. The wall of the oospore is thick and is 2 layered. The outer wall is termed the excspore and the inner the endospore. The exospore develops a dark brown colour and is thrown into a number of ridges or tooth like projections. This gives the spore a reticulate appearance.

Late in the season when the tissues of the host containing oospores rot, the oospores germinate. The oospore puts forth a vesicle into which the protoplasm moves, a number of zoospores are formed, these escape, settle down and develop the organism. (fig. 272).

There are other important types such as *Sclerospora sorghi* an obligate parasite causing the disease known as leaf shredding disease. *Plasmopara viticola* another obligate parasite causing the downy mildew of grape vine. All these have nonseptate mycelia and other characteristics of the group Oomycetes to which they belong.

THE MOLDS

Zygomycetes, General characteristics.—Many organic substances, such as cooked food of various kinds, bread, vegetables, fruits, jam, leather goods, etc., when left in damp situations speedily become covered with a felt of the threads of saprophytic fungi. These are generally white, yellow, blue, green or grey in colour and are popularly spoken of as " moulds " or " molds ".

Plant body of the Mold.—The body is made up of branched threads or hyphae, usually consisting of chains of more or less cylindrical cells united end to end. These hyphae are differentiated on the basis of function into two types (1) some serve the purpose of securing nutriment from the substratum in which they are growing, and are called *vegetative hyphae*, (2) others produce spores for propagating the fungus and these are called *fertile hyphae*. The whole mass of vegetative hyphae, the entire plant body of the mold is called the *mycelium*. In some molds the hyphae are septate. In others they are non-septate. A septate hypae is divided at intervals by cross walls or septa. This means the thread is divided into distinct cells.

In the non-septate type cross walls are wholly absent or occur only occasionally, the whole mycelium being thus made up of a more or less branched continuous tube containing protoplasm and

numerous nuclei embedded in it. Inasmuch as in the non-septate mycelium there are numerous nuclei it is multinuclear and the term *coenocyte* is sometimes used to indicate this type of cell. In the septate molds each cell has a single nucleus.

Whether or not the mycelium of a mold is coenocytic or septate is an important factor in classification; that is, the two principal groups of molds may be differentiated by this means.

There is present a cell wall and the protoplasm is made up of ectoplast, cytoplasm and nucleus. The cells frequently contain vacuoles, granules, oil globules and sometimes other inclusions.

Growth of a Mold.—It is known that all multicellular organisms grow in two ways by an increase in size of the cells and by an increase in numbers of these cells. The latter may be either *intercalary* or *apical*. In moulds showing intercalary growth, any cell may divide, each cell then increasing in size frequently with some consequent distortion of the thread. This kind of growth is rather rare. The apical method is more common and here the terminal cell alone divides, and the filament grows in length only at its tip. Branching of a hypha is due to the division of a cell nucleus followed by a budding out of a lateral filament from the cell.

Reproduction of Molds.—Molds reproduce usually by means of spores, each organism producing these spores in very large numbers. Spore production is a method of *multiplication* as well as of *reproduction*. Like the spores of bacteria, the spores of the molds are useful in carrying the organism through unfavourable conditions, and aid in its dissemination.

Spores are of two types—*sexual* and *asexual* in origin. A sexual spore results from the fusion of two sex cells or *gametes*. An *asexual* spore is one that is produced without the intermediation of sex cells. Practically all molds produce asexual spores. In some cases two or three kinds may be developed by a single species. Some are known to produce sexual spores as well.

Sexual spore.—The case of *Rhizophus* may serve as an illustration. The mycelia are of two kinds, *i.e.*, heterothallic. Two cells approximately equal in size rise from filaments lying close together enlarge and bend toward each other. Their tips are separated from the rest of the branch by the formation of cell walls. Finally the tips meet, the walls in contact dissolve, and the contents of the two cells flow together and fuse to form the spore which is called the *zygospore* (yoke spore) (Fig. 273). The immediate change noticed is the heavy membrane formed about this cell which then goes into the resting stage and under favourable conditions it will germinate and reproduce the mold.

Asexual spores of Molds.—Practically all of the molds bear asexual spores. The manner in which these are produced, their size, shape, color and septation help us in the determination and differentiation of genera and species.

Asexual spores are either borne free on the sides or ends of hyphal threads or they are produced in a specialized spore case called a *sporangium.* A spore not borne in a sporangium is commonly called a *conidium.* The stalk (specialized hyphae) bearing a sporangium is called a sporangiophore (Fig. 273) and one bearing conidia a *conidiophore.* The formation of spores in a sporangium as in Rhizopus will be discussed here. A sporangium originates as a terminal swelling of the sporangiophore or one of its branches; this enlargement is separated from the sporangiophore by the formation of a septum. This enlarges considerably. The nucleii contained within it increase in number and each surrounds itself by a bit of cytoplasm. This is enveloped in a membrane and spores are thus formed. The interior of the sporangium is in this manner more or less compactly filled with spores. Usually a structure known as *columella* is also to be found within the sporangium. This is a club shaped or hemispherical extension of the sporangiophore into the cavity of the sporangium itself. The outer wall of the sporangium is usually a thin membrane which breaks open readily when the sporangium is mature.

Spores are much more resistant to unfavourable environment such as light, heat, drying and chemicals than the hyphae that produce them. Many are well adapted for transportation by currents of air and hence it is that molds are so rapid in their spread and occurrence. When brought under favourable conditions for growth they germinate and produce mycelium.

Mucoraceae.—Is characterized by the formation of *zygospores.* The zygospores are not commonly produced by many species, hence the asexual spores and their arrangement furnish a somewhat simpler and more useful means of classification. Most of the genera produce sporangia, a few do not and in their cases asexual reproduction is by means of conidia. About eighteen genera are known. *Rhizopus* and *Mucor*, the two most important black or grey molds, will be treated here as types.

Rhizopus.—Species belonging to this genus are saprophytic and commonly met with on decaying bread, vegetables and leather. The spores are present in air. The vegetative mycelium penetrates the substrata material (bread, vegetable or a leather shoe) and soon sends up into the air long slender threads known as aerial hyphae. These grow until they come into contact with some

solid object such as the walls of the vessel; they then produce clusters of root like hold fasts, *rhizoids* (Fig. 273). These are easily

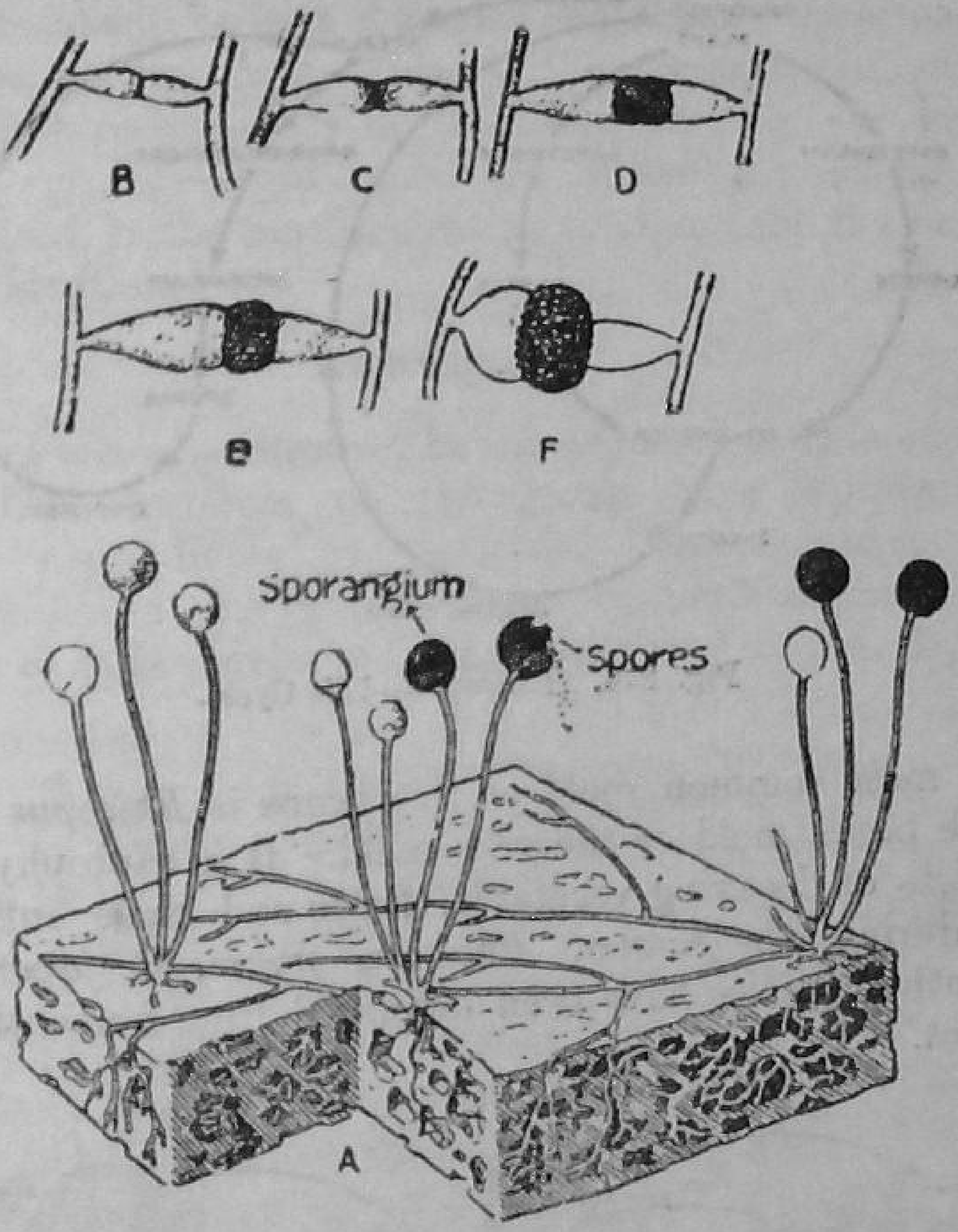


Fig. 273. Rhizopus. A. Asexual; B-F. Sexual.

made out through the glass sides of a flask or petri dish in which the mold is growing. A thread which attaches itself in this fashion often continues to grow and again throws out rhizoids. On account of its resemblance to a runner like *Centella*, such a thread is termed a *stolon*. From each of the points where the rhizoids are produced, there develops a cluster of unbranched sporangiophores. The sporangium which develops at the tip of each contains a large number of spores. When young it is white, but soon turns black, due to the ripening of the spores. A columella is present but is united through part of its length with the sporangium wall. The sporangium wall breaks to pieces readily when mature and releases the spores. The columella frequently collapses when the material is mounted in water for examination, the lower half of the hemisphere invaginates and the whole assumes the appearance of an open umbrella with the sporangiophore as the handle (Fig. 273).

Sexual.—The mode of reproduction is as already explained under the general characteristics of " Molds ".

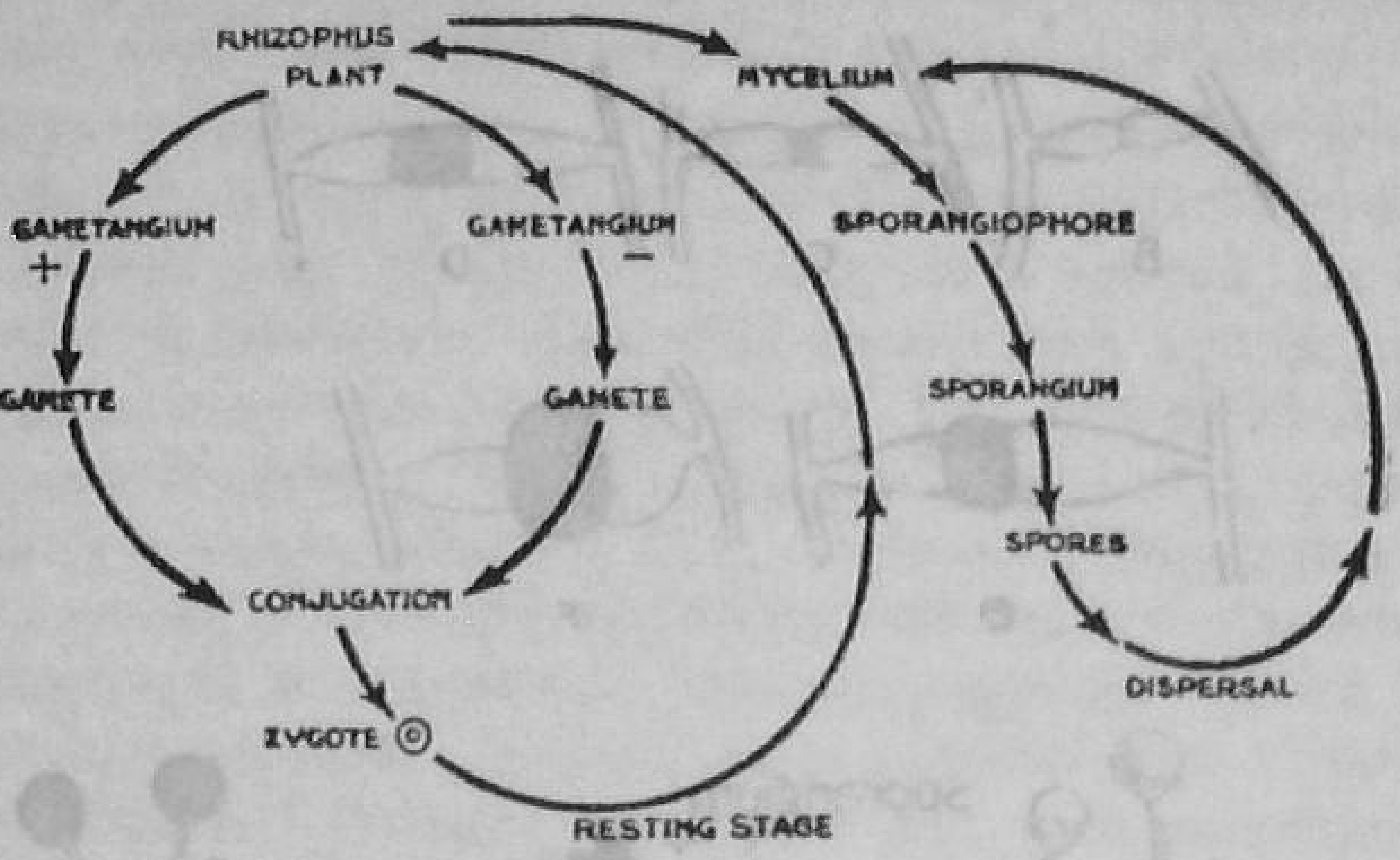


Fig. 274. Rhizopus—Life Cycle.

The most common mold of this genus is *Rhizopus nigricans* the black bread mold or the grey mold. It is saprophytic found on all sorts of decaying vegetable, fruits and male inflorescence of Jak during the season. *Rhizopus oryzae*, *R. japonicus* and several other species have been described from fermenting meals and grains.

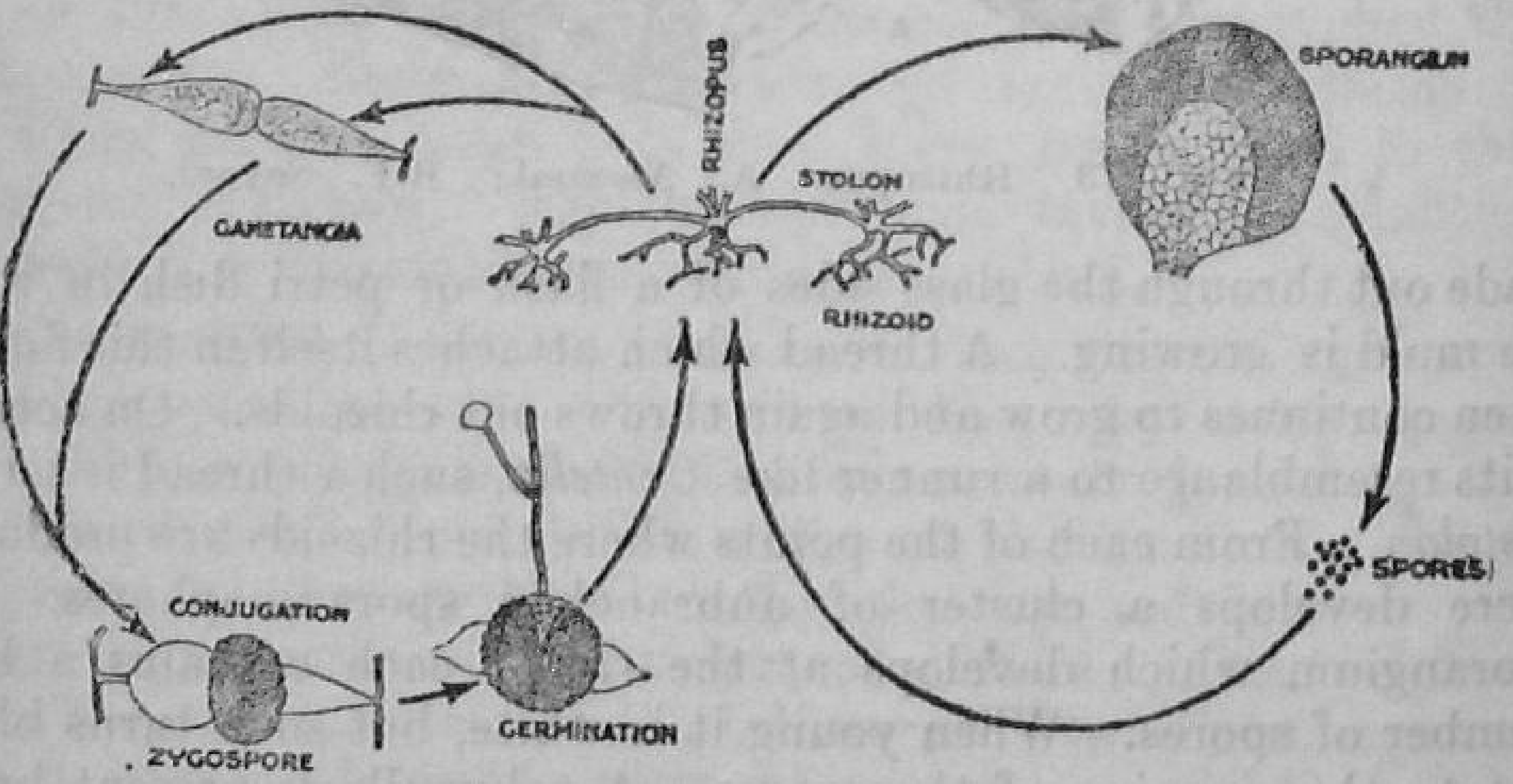


Fig. 275. Rhizopus—Life Cycle.

Mucor.—Mucors are common on decaying vegetables, fruit, bread, etc. This genus differs from the preceding principally in that there are no stolons produced. The sporangiophores do not arise in clusters but are produced singly. In some species they branch. The sporangium has a close resemblance to that of

Rhizopus, the columella being usually not as large. The sporangium wall is frequently somewhat more resistant.

To the naked eye both *Rhizopus* and *Mucor* appear as a somewhat coarse, cottony mold. Some of the species of *Mucors* produce heavy walled resting cells or *chlamydospores* in the vegetative mycelium, *e.g.*, *Mucor racemosus* (*M. rouxii*) one of the *Mucors* has been used in the saccharification of starch for the purpose of alcohol production.

Ascomycetes.

General characteristics.—The ascomycetes include over 16,000 species. The members of this group have septate mycelia. They are saprophytes or parasites. The organism may be unicellular as in the yeast fungus or multicellular and well developed as in the majority, e.g., *Phyllactina corylea*, *Aspergillus*,

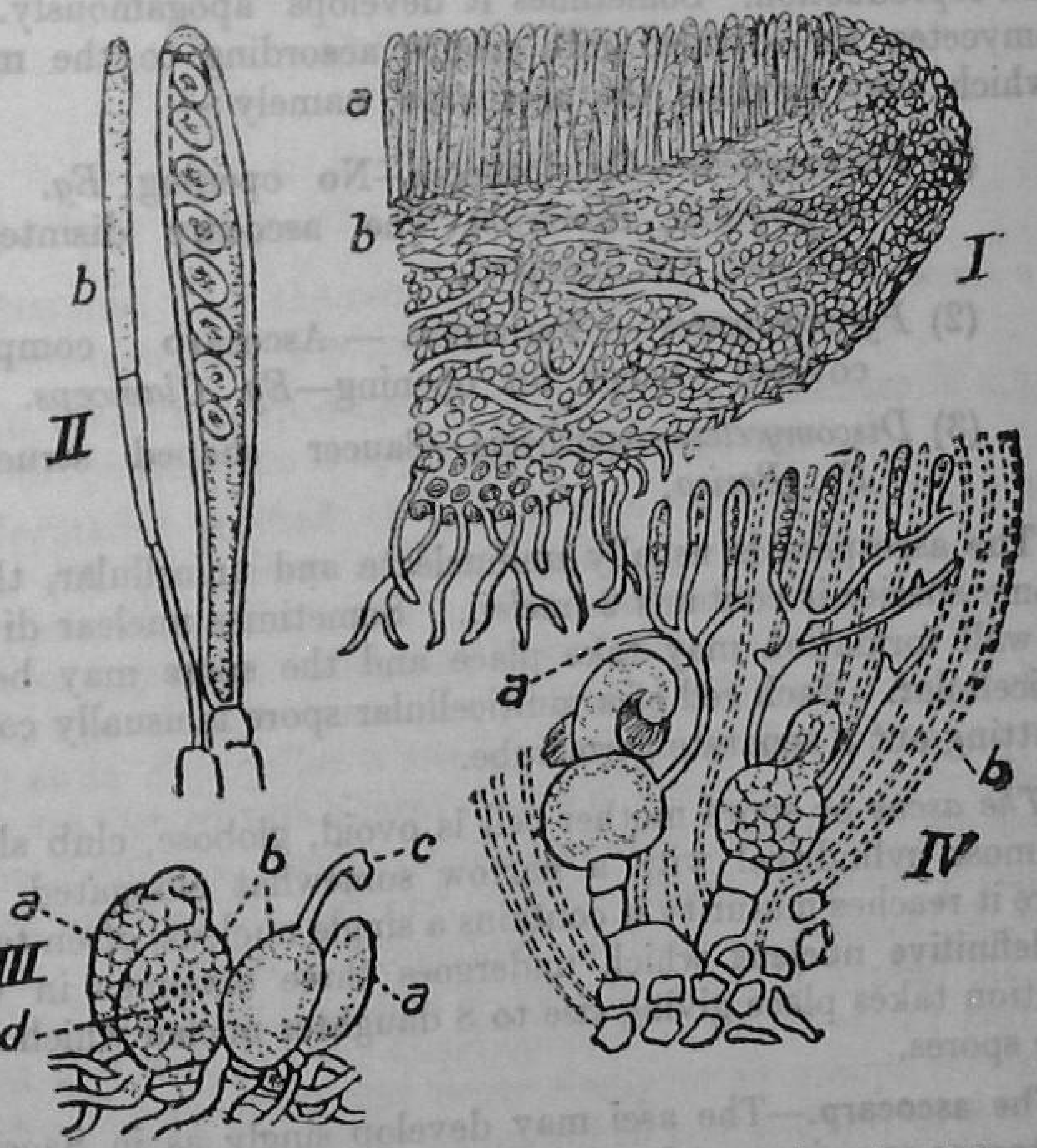


Fig. 276. *Peziza*—I. (*a*) Ascigeral layer, (*b*) Sub-ascigeral layer, (*c*) mycelium, II. Ascus with ascospores and (*b*) Paraphysis. III and IV. Pyronema Confluens Sexual Process. III. *a*) antheridium, (*b*) ascogonium. (*c*) trichogyne (*d*) male and emale nuclei IV. L. S. Young apothecium, (*a*) ascogenous branches producing asci; (*b*) paraphysis.

Penicillium notatum, *Peziza*, *Claviceps purpurea* (Ergot), etc. Many of them are economic such as the yeast, the Ergot, Penicillium and Morchella (the edible fungus-Morrel).

Reproduction :—The name *Ascomycetes* is given to the whole because of the characteristic method of reproduction by ascospores, that is by spores produced in the interior of a specialised mother cell or ascus and the spores are called the ascospores. An *ascus* is typically a club shaped or oval structure (*See* Fig. 276) with thin wall containing 8 spores normally. Sometimes the number of spores may vary due to undeveloped spores or further divisions of spores into multiples of 8 (1—128). Associated with the *asci* there are sterile hair like structures called paraphyses and these are supposed to have nutritive or supporting function. The ascospore may be smooth walled or rough walled. The ascus is usually developed as a result of sexual reproduction. Sometimes it develops apogamously. The ascomycetes are divided into groups according to the manner in which they produce the ascocarps namely :—

(1) *Plectomycetes*—Cleistothecia—No opening *Eg.* yeast, *Aspergillus*, *Eurotium* The ascocarp disintegrates and asci are liberated.

(2) *Pyrenomycetes* — Perithecia — Ascocarp completely covered except for opening—*Eg. Claviceps.*

(3) *Discomycetes*—Apothecia—Saucer shaped structures. *Eg. Peziza.*

The ascospore is usually uninucleate and unicellular, though in some species it contains 2 nucleii. Sometimes nuclear division and wall formation may take place and the spore may become multicellular. Each cell of a multicellular spore is usually capable of putting out a separate germ tube.

The ascus or spore mother cell is ovoid, globose, club shaped or almost cylindrical with a narrow somewhat elongated base. Before it reaches maturity it contains a single nucleus, often termed the **definitive nucleus** which undergoes three divisions in which reduction takes place giving rise to 8 daughter nucleii which result in the spores.

The ascocarp.—The asci may develop singly as in Saccharomycetaceae or as in most families they may rise in associated groups. They are then protected by a common wall of sterile filaments known as the **peridium** and in this way a definite fructification, the **ascocarp** or ascophore is formed. The young ascocarp is globose

and closed and the asci are liberated only by the decay or irregular splitting of its wall. It may assume a flask shaped outline opening

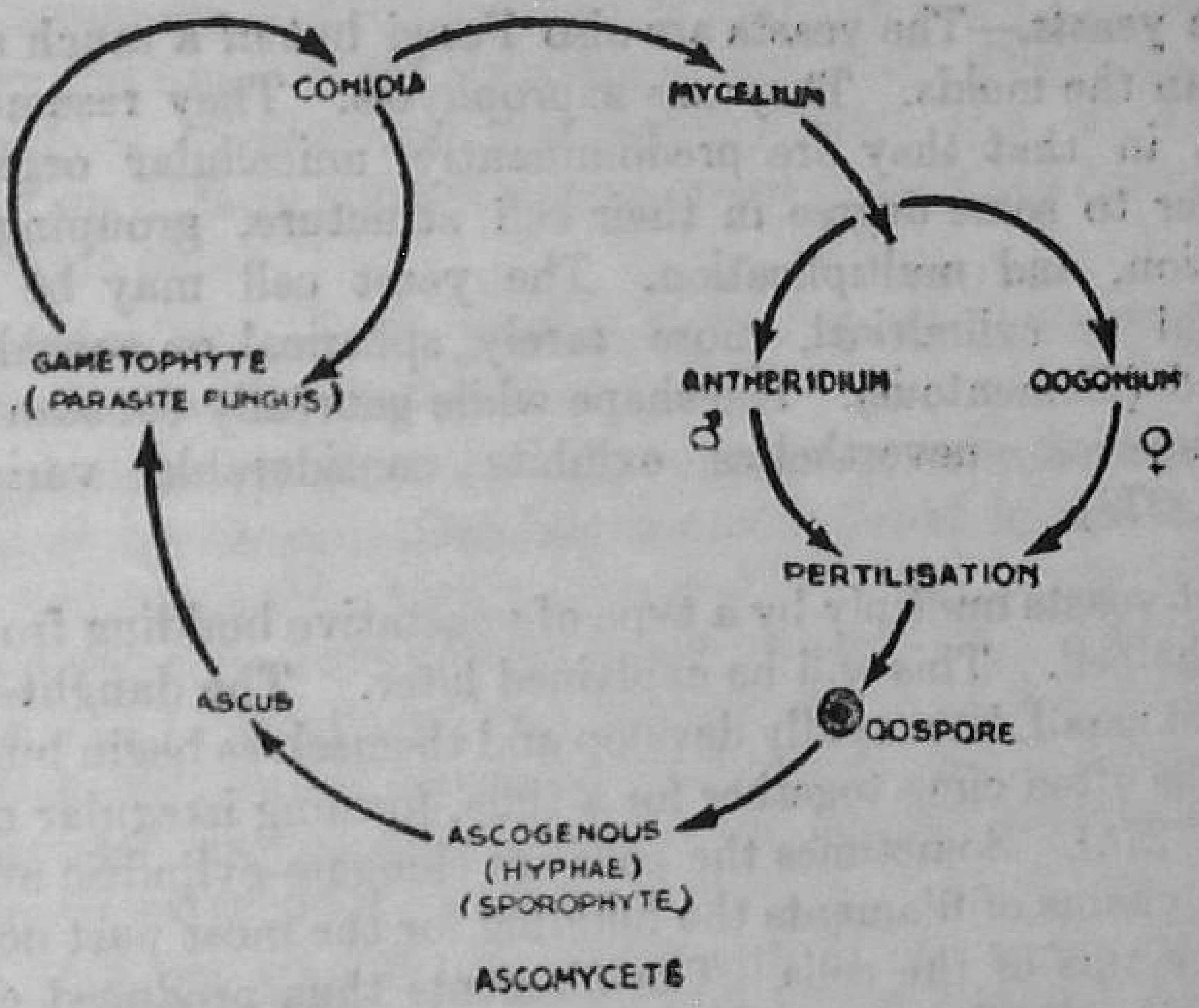


Fig. 277. **Ascomycete—Life Cycle.**

by a terminal pore the *ostiole*. It may spread out to form a cup in the concave part of which the asci are fully exposed.

To the cup shaped ascocarp the term apothecium is applied. The term perithecium is applied to the other forms.

Vegetative method of reproduction.—(1) By budding as in yeast. (2) Sclerotia-as in Ergot which are hard compact masses of hyphae where the outer hyphae are modified to form a rind. (3) Accessory spores which may be sometimes (a) single at the end of a stalk, e.g. *Phyllactina corylea* (Mulberry mildew), or (b) in chains, or (c) as in *Aspergillus* a swollen body may be formed on which stalks are formed which form chains of spores, or (d) Acervuli—the fungus forming a pseudoparenchymatous tissue which pushes out the epidermis of the host and from this tissue are stalks given each carrying a spore, or (e) Pycnidium—a kind of fructfication with a sac like form having a definite wall made up of hyphal branches. Lining this wall are the conidiophores or stalks which carry the spores. The pycnidia may occur singly or in groups (f) chlamydospores—the thick walled spores which rest and tide over adverse periods.

In all these fungi, the accessory spore stage is termed as the imperfect stage and the ascospore stage as the perfect stage.

The alternation of generations is distinct in this group. The ascus develops at the final stage of the sporophytic generation and the conidia are formed in the gametophytic generation.

The yeasts.—The yeasts are also Fungi but of a much simpler type than the molds. They are saprophytes. They resemble the bacteria in that they are predominantly unicellular organisms, but differ to some degree in their cell structure, grouping, size, sporulation, and multiplication. The yeast cell may be ovoid, ellipsoidal or cylindrical, more rarely spherical or considerably elongated (filamentous). The shape while generally constant for a given species nevertheless exhibits considerable variations. (*See* Fig. 278).

Most yeasts multiply by a type of vegetative budding from any side of the cell. This will be explained later. The daughter cells are at first small, but rapidly develop and themselves begin budding. These cells often cling together for a time, forming irregular masses (*See Fig.* 278). Sometimes the cells are elongate-cylindric and are united in chains of filaments the budding for the most part occupying at the tips of the cells. The filaments thus produced closely resemble the hyphae of molds, and constitute a type of plant structure intermediate between that of the typical yeast and the mold. Some yeasts do not bud, but multiply by fission as do the bacteria.

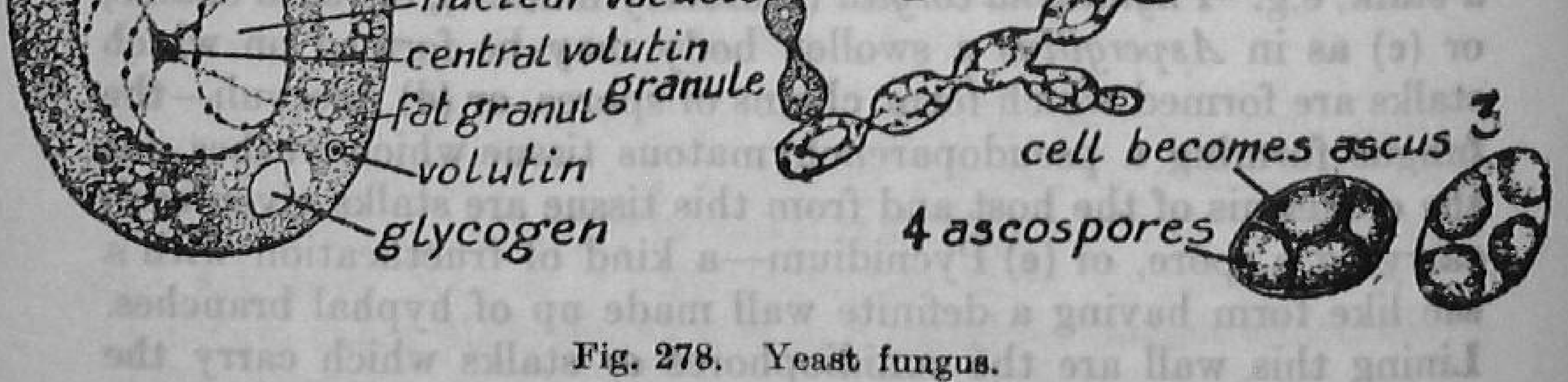


Fig. 278. Yeast fungus.

Structure.—The cell wall is a firm membrane made up of a substance frequently called yeast cellulose. It is believed to be carbohydrate in chemical composition. The wall is thickened in old cells. Gelatinous capsules of essentially the same character

as those found among the bacteria may be found surrounding a yeast cell. **Flagella are never produced : and the yeast cells are never motile.**

Cell contents.—The protoplasm is made up of (1) the ectoplast, (2) the cytoplasm, and (3) the nucleus (Fig. 278). There are vacuoles, granules of glycogen (a carbohydrate) and oil globules. The function of the ectoplast was discussed under bacteria and they are the same here.

Reproduction.—True yeasts reproduce in two ways: (1) vegetatively, and (2) by means of spores.

Vegetative reproduction.—The vegetative reproduction is by budding or by fission. Budding is accomplished in this way. A minute protuberance appears on one side of the mother cell, the nucleus divides, and one portion passes into the bud. The bud then enlarges and is separated by a constriction from the mother cell. At first no cell wall is demonstrable, but this soon develops. The daughter cell may separate at once and become entirely free or it may remain attached for a time.

Multiplication by fission is met with in the genus *Schizosaccharomyces*. One of the species *Schizosaccharomyces octosporus* is the active agent in the fermentation of an African beer.

Spore production.—All the yeasts produce spores. The yeasts are to be regarded as simple perhaps primitive members of Ascomycetes (sac fungi). This group is characterised by the formation of a number of spores within a cell frequently one that has been *somewhat differentiated* for the purpose. In the case of the yeast, however, the spores develop within the cells that are little or not at all different from the vegetative cells. A cell containing spores is termed an ascus or sac, the spores are called ascospores, or more rarely **endospores.** Sometimes before the formation of the spore two cells come together. They produce small outgrowths which come into contact. Fusion takes place between the nuclei and then they divide.

Ascospores germinate by swelling or by bursting the spore wall and budding.

Saccharomyces.—This genus is of great economic importance, as it includes a large proportion of all the commercial yeast. Almost all of the species are active in fermentation of sugars with the formation of alcohol and carbon dioxide. For purposes of demonstration of yeast, a drop of country toddy may be mounted and examined with the low power of the compound microscope. The cell, shape, structure, budding, etc. may all be easily made out.

Most of the yeasts are of economic importance in the fermentation industries, such as bread making, brewing, wine making and commercial manufacture of alcohol.

Sacharomyces cerevisiae.—Brewers yeast or Bakers yeast is the common bread yeast having large spherical or ovoid cells. *Sacch. ellipsoideus* is the wine yeast which has ellipsoidal or short oval cells, and the name *Sacch. pasteurianus* is given to all long or cylindric celled yeasts.

Food yeast which is produced on a commercial scale is dried *Torulopsis utilis.* It is a combination of high-class proteins with vitamins of the B complex of which it is one of the richest sources. Food yeast is of particular value for people in most part of the tropics where food value is poor. It is easy to manufacture, has a superior flavour and palatability. Because of food yeast being rich in B vitamin, it is very good in human nutrition for child, adult and old people. This is easily grown in molasses or 1·1 per cent of sucrose solution. Alcohol formation is very little and the organism grows. The solution is decanted, cells separated, centrifuged, dried and powdered. The powdered stuff contains 50 per cent of protein and Vitamin B2. It is packed carefully in paper packets or bottled and sold as such.

Eysiphaceae.—The members of this group are popularly known as **powdery mildew or white mildew or blight.**

They are obligate parasites on the leaves, young shoots and inflorescence of flowering plants. When the conidiospore or ascospore germinates the fungus forms abundant superficial mycelium of uninucleate cells, which forms a white, web like coating over the leaf and sends haustoria into the epidermal cells of the host. In the simplest cases the haustorium is a slender tube which swells inside the host cell; in others it is branched, forming finger like processes and often provided with an external disc or *appressorium* from which or from the mycelium in the neighbourhood of which the haustorium proper arises and pushes into the epidermal cell. In *Phyllactinia corylea* the branches of the aerial mycelium enter through the stomata, ramify the intercellular air spaces and send haustoria into the neighbouring cells.

Propagation.—They propagate in warm weather by rather large, oval, uninucleate conidia (Fig. 280) produced in rows on unbranched conidiophores. Before the connection of the conidial with the ascigerous stage was recognized the generic name **oidium** was used for the former. The perithecia are more or less globose without an ostiole, furnished with conspicuous appendages. In

Phyllactinia the perethecia bear stiff, pointed hairs with swollen bases (Fig. 279).

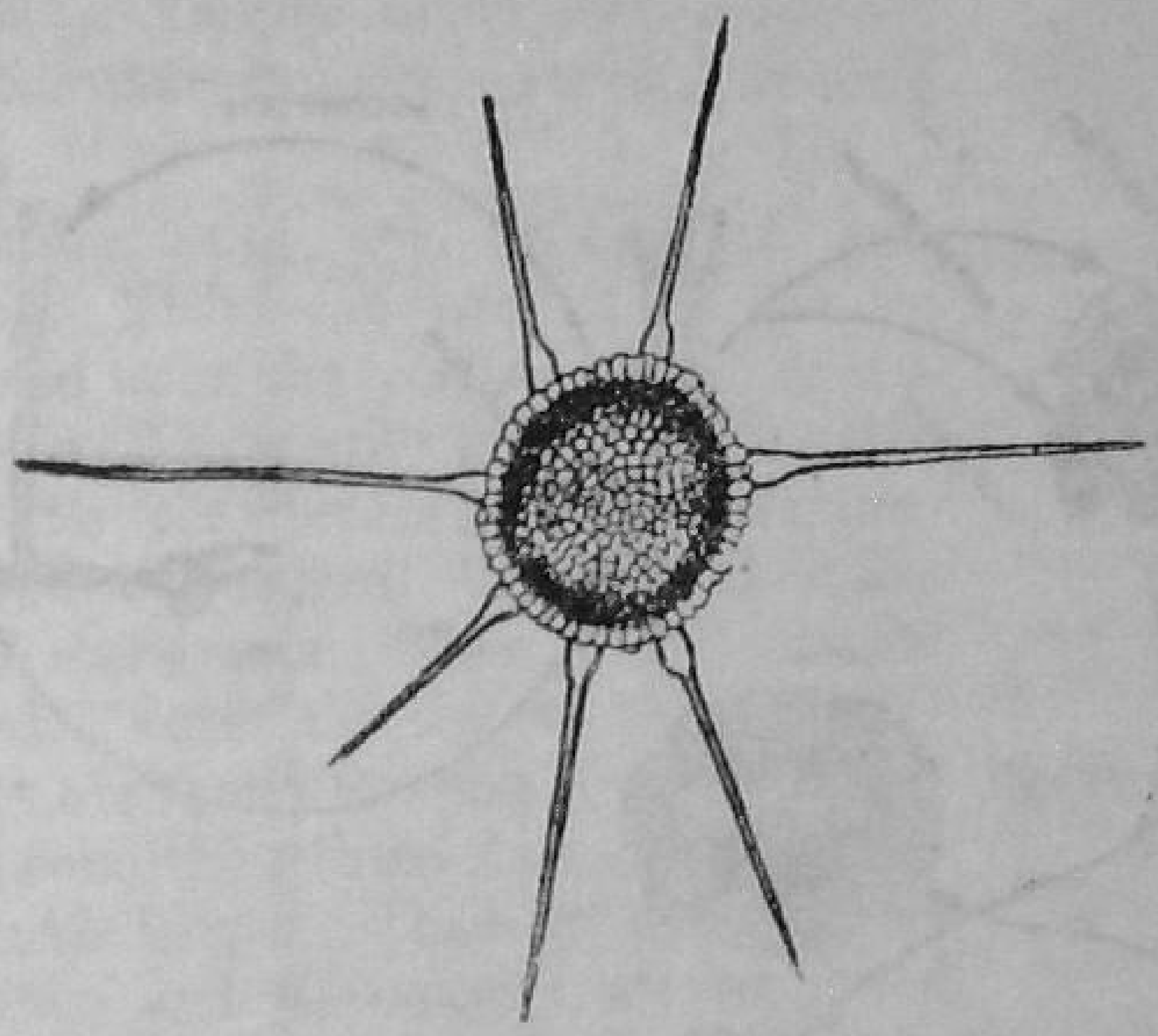


Fig. 279. Perithecium of *Phyllactinia*.

Phyllactinia corylea—Obligate parasite which attacks mulberry and forms powdery patches on the under surface of leaves. The conidium is club shaped and one celled. Multiplication by conidia takes place in summer and in winter the ascocarps are formed. The ascocarps are formed on the under surface of the leaf. They are spherical reddish brown bodies. The ascocarp arises often after sexual fusion. The hyphae form the antheridium and the oogonium. Fertilization takes place. After this a number of branches are formed which cover up the internal structure. These are the ascogenous hyphae from the terminal cells of which the asci

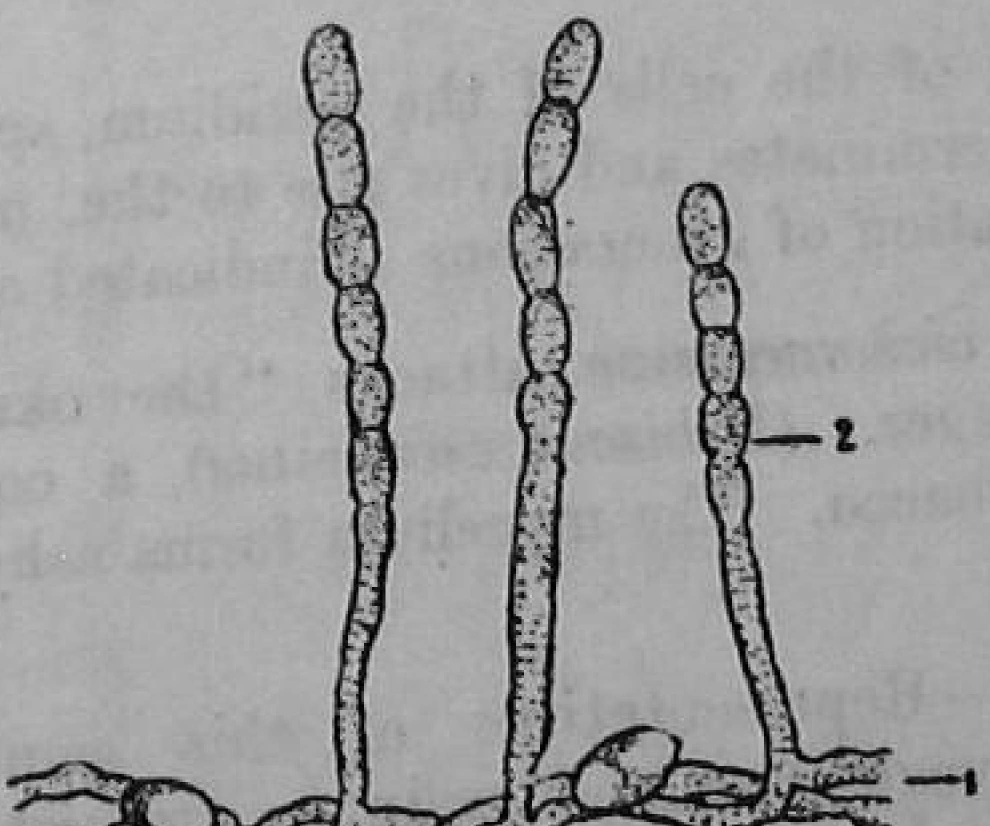


Fig. 280. Oidium-Conidia.

are formed. The asci arrange themselves and the whole structure becomes protected by hyphae (peridium).

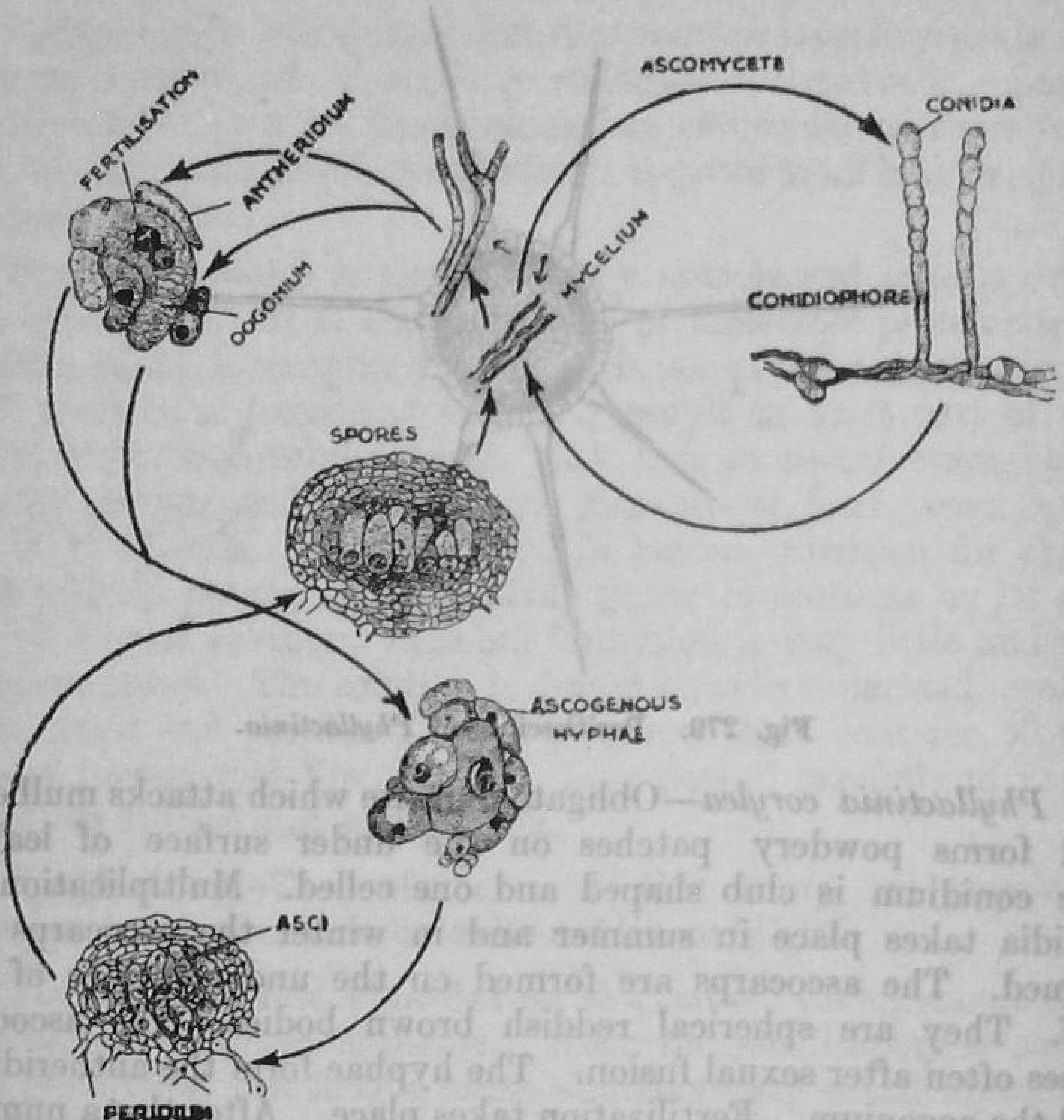


Fig. 281. Life cycle—Alternation of Generations.

From some of the cells of the peridium, spines are formed. The ascospore germinates and gives rise to the mycelium. There is a clear alternation of generations as indicated above (Fig. 281).

Erysiphae cichoracearum attacks "the okra" "Bhendi" or the ladies finger. (*Hibiscus esculentus*), a common vegetable crop and the tobacco. The mycelium forms ashy patches on the leafy surfaces.

Aspergillus.—Representatives of this genus are common upon decaying vegetables and grain as greenish yellow, orange, brown or black velvety or powdery molds. The spores are in the air and therefore infect organisms which are exposed to dust.

Many of the species produce ascospores. The asci and ascospores are borne in spherical golden yellow perithecia, usually lying closely oppressed to the vegetative mycelium. All members of *Aspergillus* are easily made out because of the characteristic method of bearing conidia.

Fig. 282. Aspergillus Conidia.

The conidiophores are unbranched and usually long. They are swollen at the tip (Fig. 282) and upon the surface appear numerous short stalks usually set close together giving to the conidiophore the appearance of a war club with spikes. These small stalks are termed **sterigmata.** They may be single or branched. From the tips of these sterigmata spores are found forming chains. Under favourable conditions these chains may develop to considerable length. There are many species of *Aspergillus* and the species are separated into groups on the basis of the color of the mature spore masses.

Aspergillus glaucus is one of the commonmost of the green spored species on canned fruits, jellies and moldy grain. *A. fumigatus* produces a fatal pneumonia in birds when inhaled. *A. niger* is of importance because of its active fermentive ability in sugar solution.

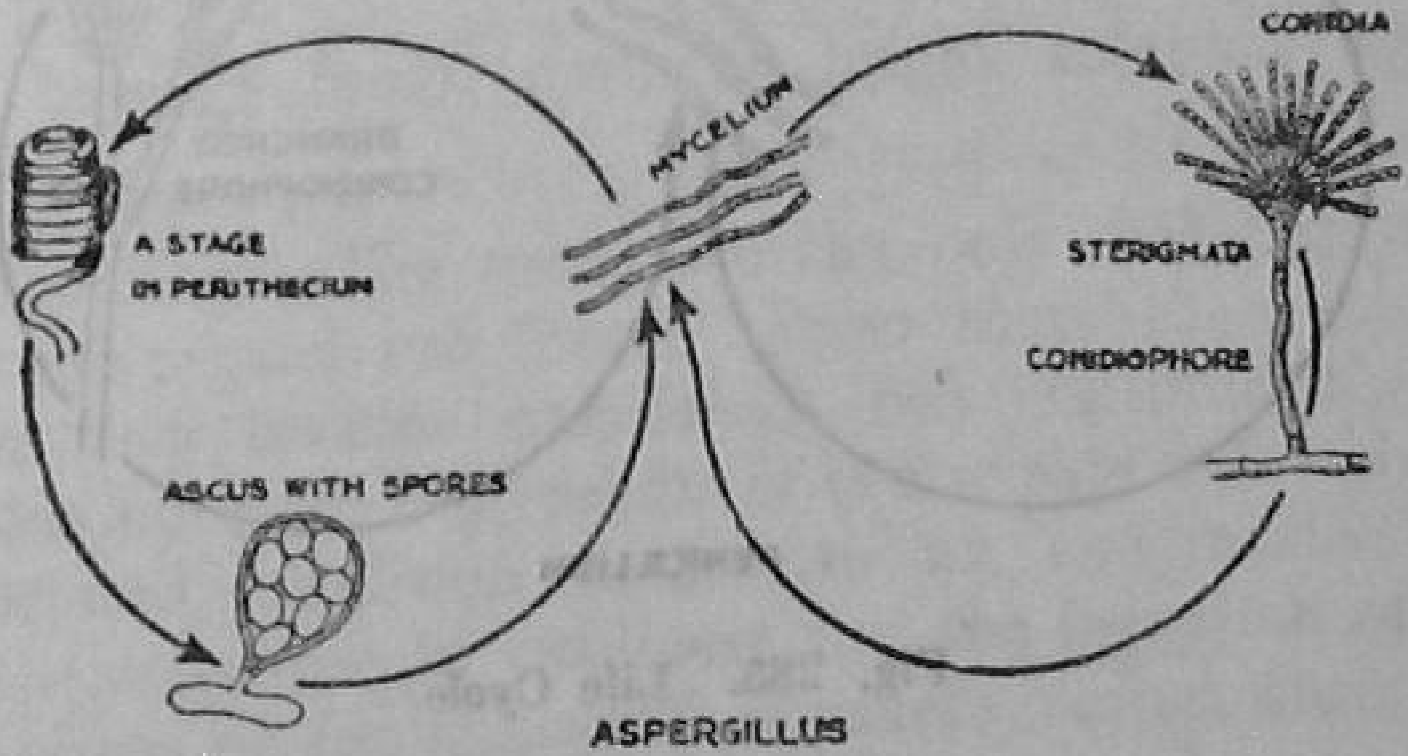


Fig. 283. Life Cycle.

Penicillium—This is closely related to *Aspergillus*, although the formation of perithecia is very rarely observed and possibly never occurs with many species. Among molds, representative

of *Penicillium* are most common. They are the blue green molds observed on oranges, lime, apple and other fruits, vegetables, preserves, etc., on almost any moist organic matter. *Penicillium* is differentiated from *Aspergillus* by the manner in which the spores are borne. The vegetative mycelium penetrates the substratum and later sends up erect aerial hyphae as conidiophores. These branch one or more times in whorls, giving rise to a terminal cluster of parallel hyphae and each of these ultimate branchlets is to be regarded as a *sterigma.* From each of them a chain of conidia is abstracted.

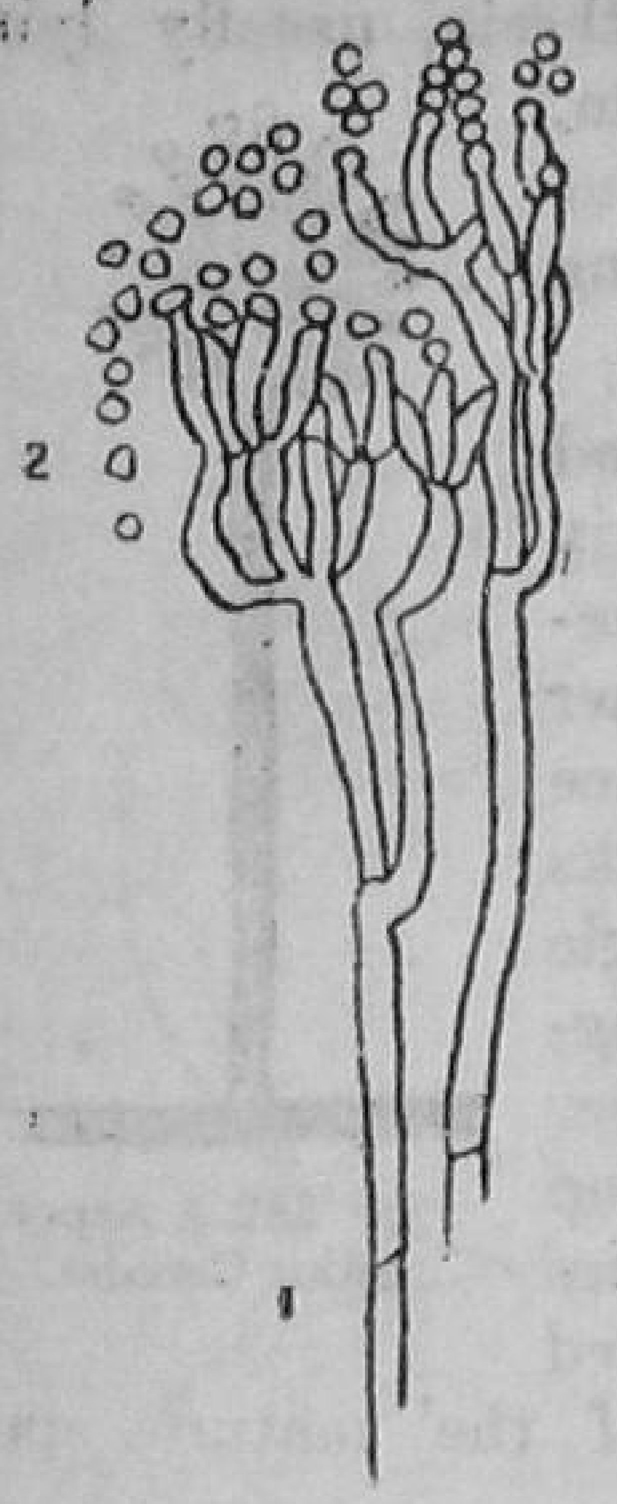


Fig. 284. Branched Conidiophores and Spores.

The branches and conidia together resemble a camel hair brush and hence the name *Penicillium* (Lat. a little brush). Several of these are of importance in ripening cheese.

Penicillin, perhaps the most valuable chemotherapeutic agent yet known to science is obtained from *Penicillium notatum.* Penicillium occupies at

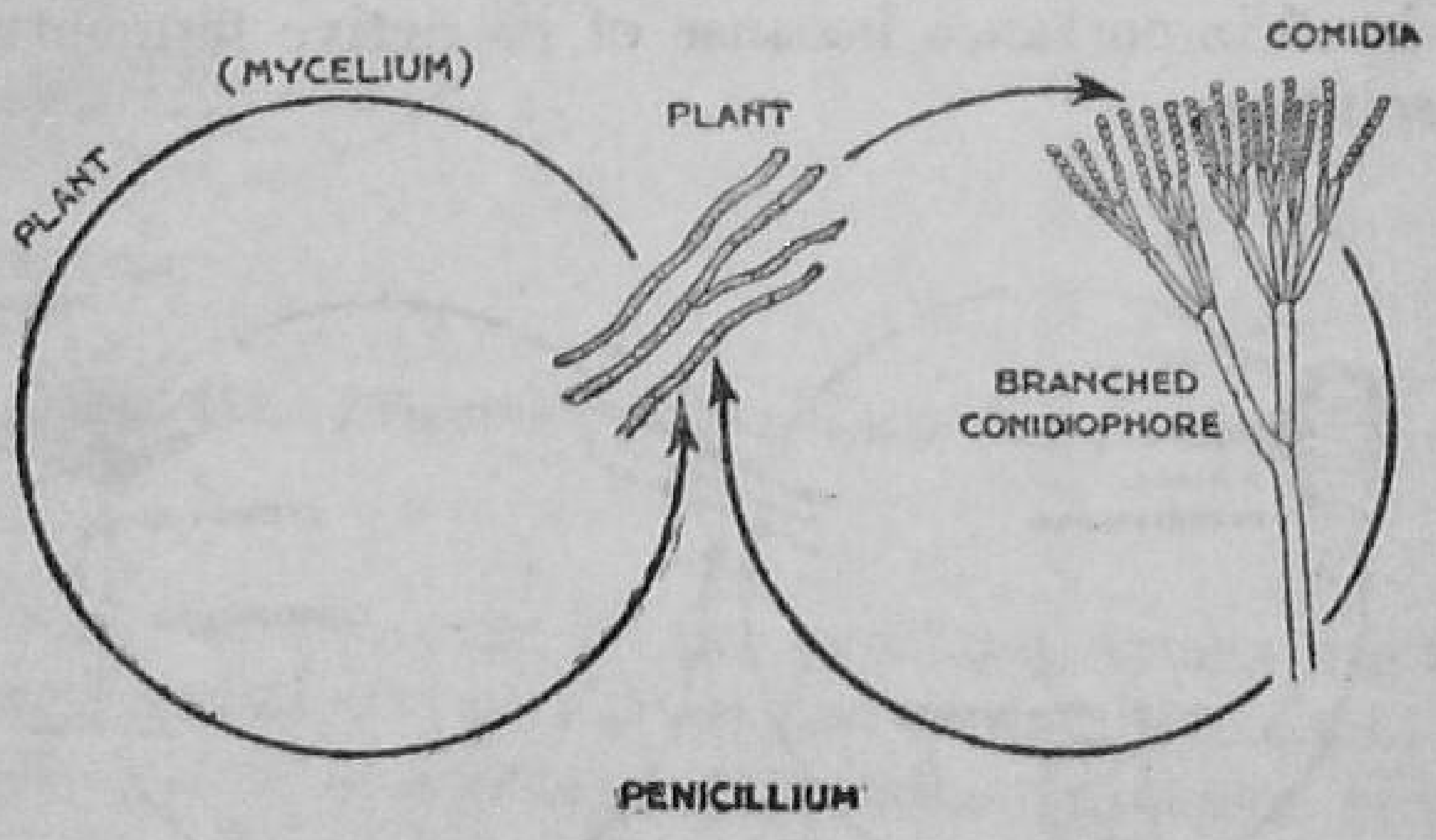


Fig. 285. Life Cycle.

present a very unique position among antibiotics in combining great antibacterial power with very low toxicity.

BASIDIOMYCETES

The Basidiomycetes is a fairly large group and includes over 14,000 species possessing a well developed mycelium which among

higher forms as, for example, in mushroom, Bracket fungi and puff balls builds up an elaborate fruit body or sporophore.

The Basidium.—These fungi are characterised by the fact that the principal spores, the basidiospores are borne externally on the mother cell or basidium. The young basidium contains two nucleii and these fuse. The fusion nucleus divides, providing the nuclei of the spores. The spore is formed at the end of a stalk, the sterigma. Two successive divisions in the basidium constitute a meiotic phase. The Basidiomycetes are divided into the following groups: (1) *Autobasidiomycetes* (Mushroom group). The basidia are without septa and two to four spores arise from the basidium. (2) *Protobasidiomycetes* (Rust group). The basidum is divided into four cells, each of which gives rise to a single spore. The walls are transverse in the *Uredinales* and *Auriculariales*, longitudinal or oblique in the *Tremellales*. (3) *Hemibasidiomycetes* (Smut group). Septa may or may not be present in the basidium but more than two divisions follow nuclear fusion and more than four spores are produced.

In the Ustilaginales and in most of the Uredinales the contents of the basidium are at first enclosed in a thick wall forming the brandspore or teleutospore cell which becomes detached, serving as an additional means for the distribution of the plant. The spores germinate and produce the *promycelium* on which the basidiospores are formed.

The Basidiospores are unicellular, rounded or oval, asymmetrically attached to their sterigmata usually with a smooth, rather thin wall.

In gill bearing fungi, dark or bright coloured spores are common.

Reproduction:—The rusts are the only basidiomycetes in which sexual organs are found. Even there the nuclei do not fuse when they become associated, but continue their development side by side. A mycelium of bi-nucleate cells is developed. The associated condition comes to an end in the basidium where the nuclei fuse in readiness for the inception of meiosis. The sporophyte or diplophase thus shows paired nuclei instead of nuclei with the double number of chromosomes.

The sporophore.—The Hemi-basidiomycetes and Uredinales are without exception obligate parasites with rather a delicate, endophytic mycelium and do not build a sporophore. In the Autobasidomycetes the sporophore is large, often with a central stalk the **Stipe** distinct from the **pileus** or cap and with a fertile

region limited to the surface of teeth or of lamellae or gills or to the interior of deep pores or of closed chamber.

Hemibasidiomycetes are made up of 2 families:—(1) the *Ustilaginales*—the smuts and (2) *Tilletiaceae*—the Bunts or stinking smuts.

Ustilaginaceae.—These are the brand fungi or smuts. Obligate parasites on the higher plants giving rise in the tissues of the host to thick walled, usually dark coloured resting spores termed the *brand spores* or *smut spores*. *Sphacelotheca sorghi* causes the short smut of sorghum or grain smut. The symptoms are to be noted in the earhead. In the place of grains, elongated small grey sac like structure are noted. Each sac is called a sorus the outer wall of which is partly ovary wall and mostly of fungal hyphae. In the middle there is a short process which is called the *Columella* which is not affected by the fungus. The columella represents the remnants of the host tissue. Between the wall of the sorus and the columella the whole space is occupied by smut spores. Each spore is spherical, brown in colour and has a definite wall. When the earhead is thrashed these stick on to the healthy grains and infect them when they germinate. The smut or brand spores are chlamydospores morphologically. They may germinate immediately or even after several years. The spore on germination gives rise to a *promycelium* or *Basidium*. From each of these 4 cells small colourless *sporidia* (Fig. 286) are formed one after another. These are the basidiospores. These are unicellular, uninucleate, colorless, thinwalled. These are shed and these produce germ tubes which infect the host at the mesocotyl region. The fungus grows inside the seedling in the intercellular spaces and keeps up with the growth of the plant. In the end, the fungus enters the ovary and produces the sori. It is only then the disease is detected.

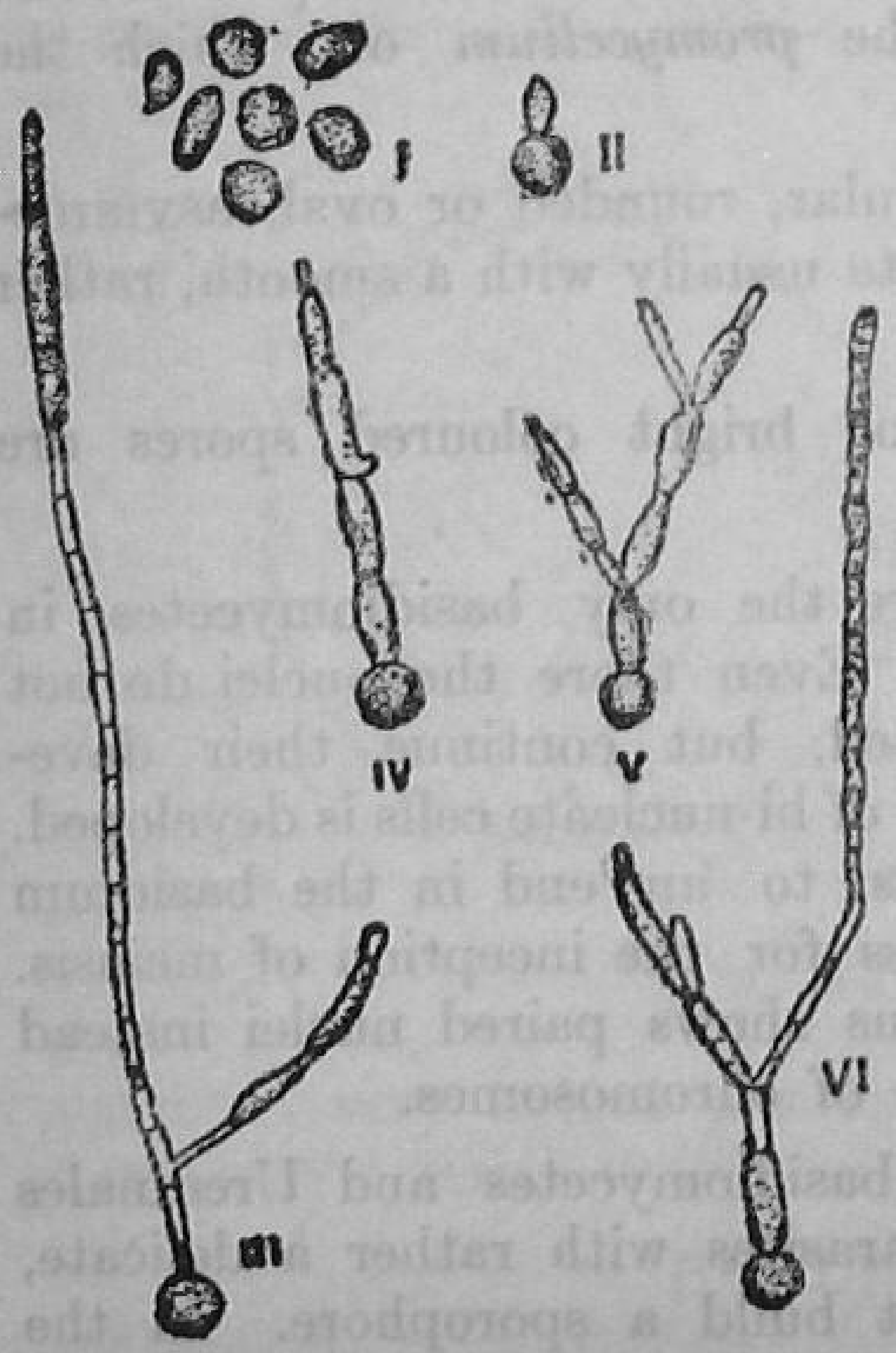


Fig. 286. Smut—Germination of Spore.

When placed in sugar solution the sporidia multiply by budding. Sometimes two sporidia fuse and a binucleate celled mycelium is formed.

The sporidia represent the *haploid* generation and the *diploid* phase starts after the fusion.

Loose smut of wheat.—*Ustilago tritici.* The symptom is in the earhead as in the short smut of cholam. The diseased plants are shorter and most portions of the spikelet become converted into sori. Diseased grains appear like healthy ones and when they are sown, the fungal spore germinates and attacks the plant and converts the spikelets into sori. The spores are blown by the wind on to the stigmatic branches of healthy flowers. The infection is in the flower and not in the seed.

There are various kinds of smuts, smuts being very common on members of Gramineae. There is the sugar smut in which case the sugarcane produces long whip like shoots; the smut of rice where the leaves are affected; smut on *Setaria italica* (*Tenai or Korra*), etc.

Protobasidiomycetes.—The rust fungi form a very important group of this class of fungi. The rust fungi include about 1700 species and are without exception *obligate* parasites on the stems and the leaves of vascular plants, usually on angiosperms or gymnosperms but in a few examples on ferns. The basidia are transversely septate.

Black rust of wheat—*Puccinia graminis.*—This fungus has got several kinds of spore formation. One can see in the month of December when the infection is on a number of elongated blister or pustules on the leaf, leaf sheath and stem of the wheat plant. These burst very soon and expose brown spores. The pustules are called, *uredosori*. They are so called as they produce the characteristic **uredospores** which are oval or elliptical in shape, one celled and brown in color (Fig. 289). Each spore is produced on a stalk. The sorus is formed underneath the epidermis and when the spores are formed, the epidermis is pushed up and blisters are formed. These burst and expose the spores. The outer wall of the spore has fine spinescent projections. In the wall there are four thin spots which represent the "germ pores." When the spore germinates the germ tube comes out through this pore.

The uredospores are formed early in the season and help in the rapid infection. The spore enters through the stoma, penetrates the tissue and continues to grow inside and forms another sorus. These spores are the first type of spores to be produced. At the

end of season another type of spore is produced. They may be formed at the old sorus or in different places. When these spores are formed the sorus becomes black. They are **two celled** and **thicker walled** than the uredospore. These are called **Teleutospores** and the sori **Teleutosori.** When wheat earheads are harvested some of these remain dormant with the grains. When in the next cold season they germinate each cell produces a basidium with 4 cells. Each cell of basidium gives rise to a spore. Thus four basidiospores or sporidia are formed from each basidium. Basidiospores are easily shed. They cannot infect wheat. They infect an alternate host namely the *Berberis vulgaris* (the Barberry). On this it produces a reddish leaf spot which when closely examined shows a number of spines. Here it produces a kind of reproductive body, *i.e.*, namely a spermagonium an oval flask shaped body with a wall which is made up of closely interwoven oppressed, hyphal masses. Inside it are paraphyses, mixed with small hyaline spores. The spore is uninucleate and called as *spermatium*. The spermatia are of two kinds + and —. Each spermagonium produces one type of spermatia. When a basidiospore infects the leaf it produces + spermagonium and in the other case a — spermagonium. From the outside of spermagonia a honey like fluid is found to attract insects which spread the spermatia and bring

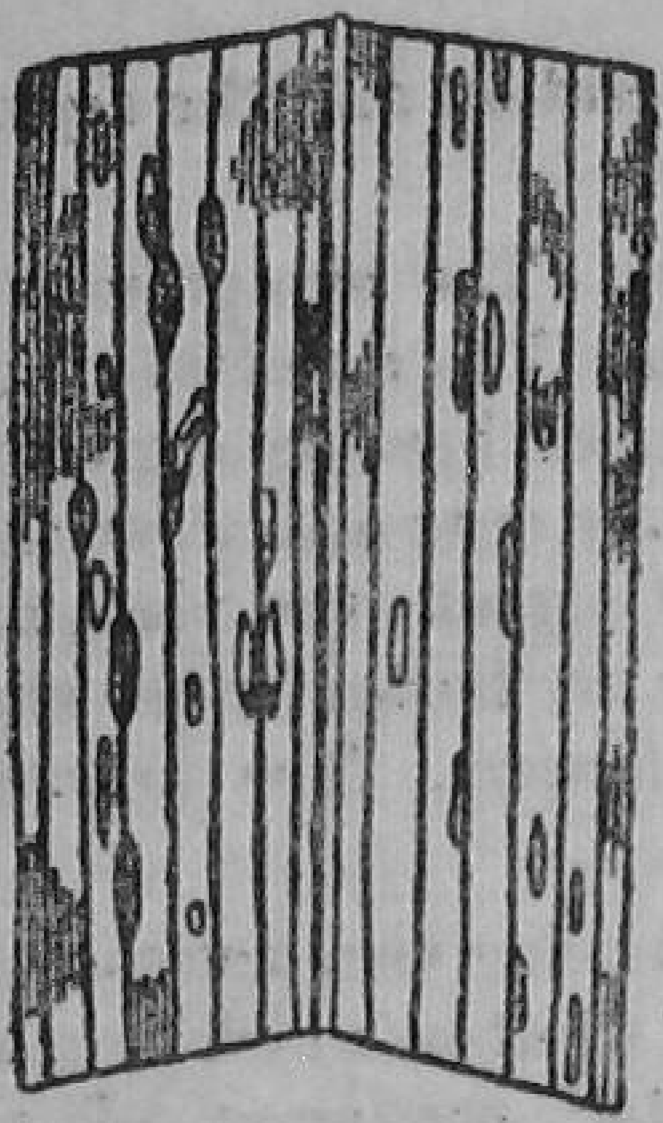


Fig. 287. A bit of cholam leaf with Rust-spots.

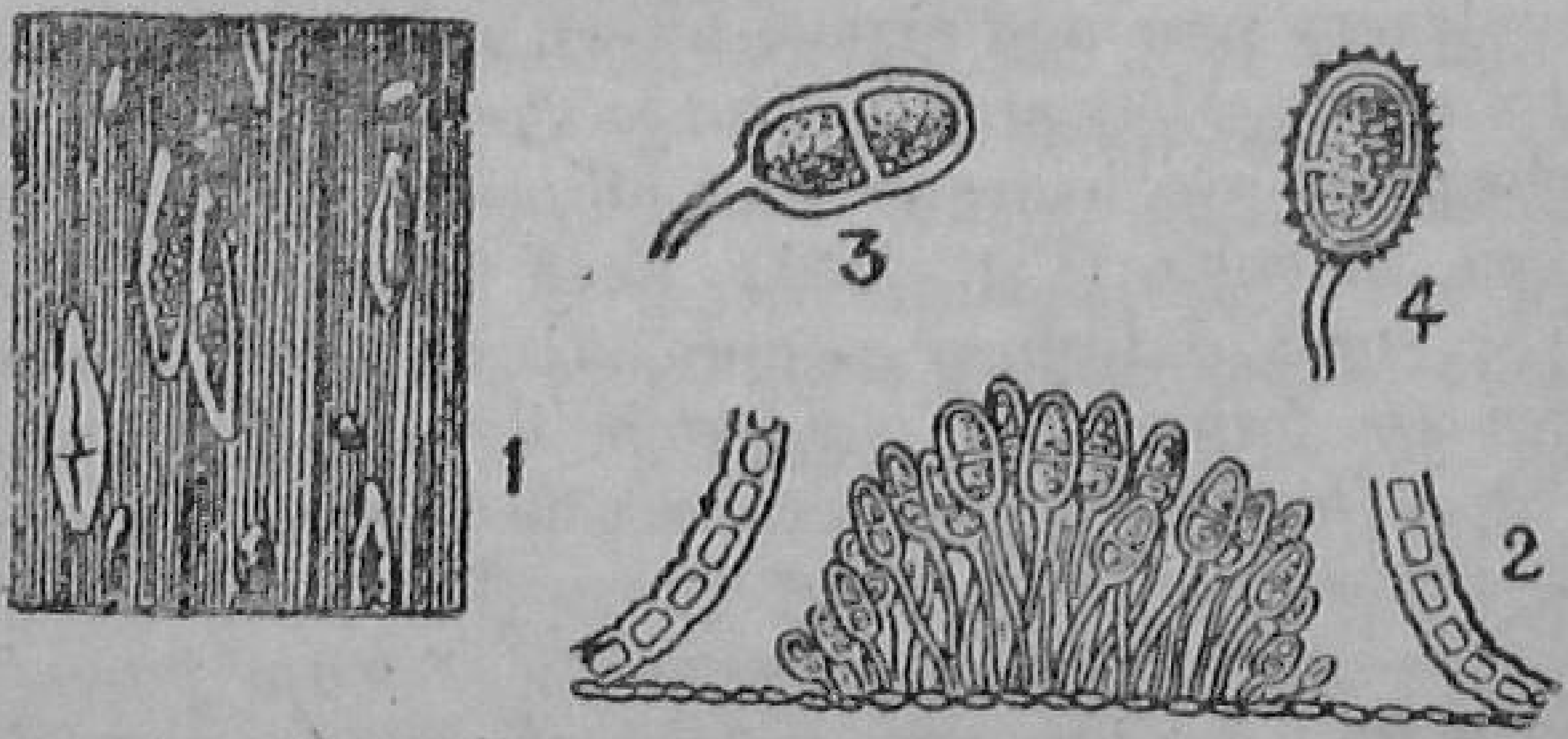
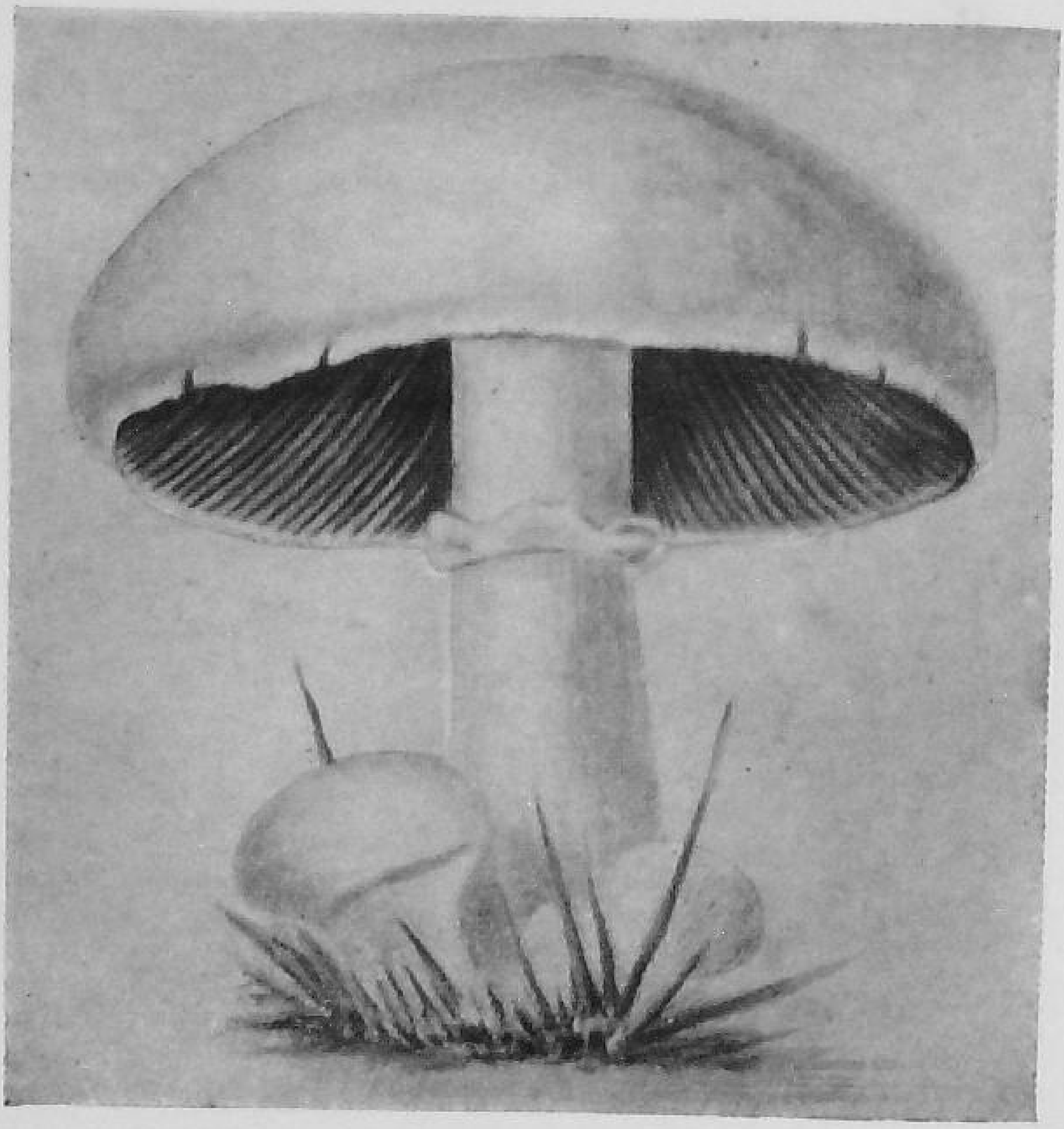


Fig. 288. Uredospores and telentospores of *Puccinia* purpurea. 1, bit of a leaf with pustulas of spores; 2. vertical section of the pustule showing telentospores; 3. telentospores; 4. uredospores. 3 and 4. highly magnified.

about the combination of + and — spermatia. When fusion takes place another type of reproductive body is produced directly in the



MUSHROOM

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undersurface of the leaf. When examined a number of cup shaped projections are made out. These are called the *Aecidia* (singular—Aecidium). These produce the **aecidiospores.** The aecidium has an outer wall made of sterile cells and the wall is called **peridium.** From the base of the aecidium projects a layer of elongated cells known as stalk cells. At the top of the stalk cell spore mother cells are formed. Each undergoes division into two, the upper becoming the spore and the lower the inter-calary cell. Each *aecidiospore* is one celled, circular and binucleate. They are carried easily by wind. The spore germinates producing a germ tube. They cannot infect *Barberry.* They infect wheat, barley, etc. The fungus develops uredosori on the wheat or barley. A rust like this which has two alternate hosts is termed a **Heteroecious** one. There is a distinct alternation of generations. The sporophyte is parasitic on wheat and the gametophyte on Barberry.

The rusts form one of the worst diseases of cereal crops. It was first thought that if one of the hosts-the Barberry-wasstr deoyed the fungus could be got rid of. So the "Barberry Laws" were passed which enforced the destruction of this host. It was found that this did not improve matters and that the fungus thrived because of the uredospores. The uredospores were able to survive in sheltered places where the temperature was not so low.

All the rusts do not produce all the types of spores. Some produce only *uredospores,* some produce *teleutospores* and no *uredo.*

There are physiological races in this fungus. The different races will affect different crops. The races are got by hybridization. All splittings and combinations may be formed and consequently new races result.

Another important fungus of this group is *Corticum salmonicolor* which is responsible for pink disease, a serious affection on rubber, tea, coffee, mango, etc. The attack is mostly in cortex and bark. This disease is also called "Die back" as the tissues die backwards from the affected place.

The Mushrooms—*Psalliota Campestris* (Agaricus Campestris) belongs to the family Agaricaceae. They are fleshy fungi. This consists of a vegetative portion found inside the soil and is made up of mycelium. Sometimes branched septate hyphae are united to form a thick cord like *rhizomorph.* The fungus makes its appearance after the rains, commonly in or near manure heap, lawns, etc. It is also cultivated as it is edible. There are mushroom farms in England, France and America. It is not quite a success

in the plains. It can be grown in the hills in South India. The fungus is a saprophyte. When favourable conditions occur the sporophore is produced. The sporophore is the reproductive body. It is this that we call as the mushroom. The mushroom fruit body consists of a stalk which is called **stipe** on the top of which there is the umbrella like portion called *Pileus* (Fig. 290). The color is usually white. The stipe is made up of a number of hyphae arranged parallel to one another. In the upper half of the stalk a ring termed *annulus* occurs. The cap is thick and fleshy. The stalk is attached to the middle of the cap on the under surface. There are a number of plate like structures on the under surface radiating from near the attachment of the '*Pileus*' towards the circumference. These are called '*gills or lamellae*' (*see* Fig. 291). Some gills may extend only half way and not to the circumference. Each gill has a knife blade like appearance in section. The centre of each gill is occupied by loose hyphae almost parallel to one another called *Trama*.

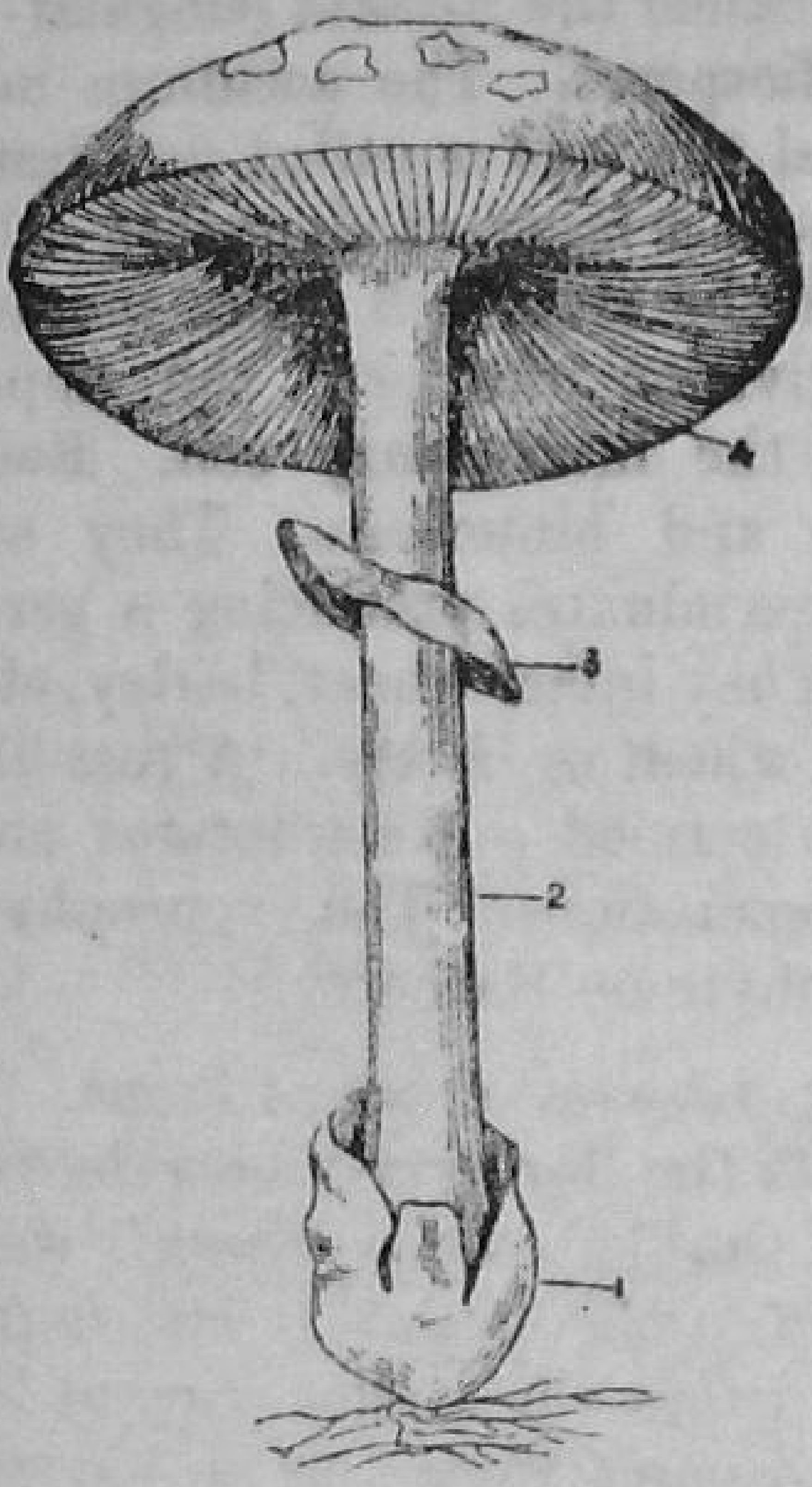

Fig. 289. Volvaria diplasia.

As they approach the surface they give rise to a compact layer of small cells called '*Sub-hymenium*'. Outside this layer is the '*Hymenial*' layer (Hyme-marriage). Hymenial layer is the layer of basidia. Each basidium is club shaped and bears four spores. The basidiospores have stalks or sterigmata. The basidiospores is one celled and purple. The color of spores and the number of spores produced in each basidium go to distinguish the mushrooms systematically. In some there are besides the basidia paraphyses. Millions of spores are formed by a single sporophore. Hence the fungus multiplies most rapidly. The spores are dispersed by wind and under favourable conditions they germinate and produce the mycelium.

2. *Volvaria dipiasia.*—This is much better suited for the tropics than *Psalliota Campestris*. It is a tropical fuugus found in India, Burma and Malaya. It is called the '*Paddy straw*

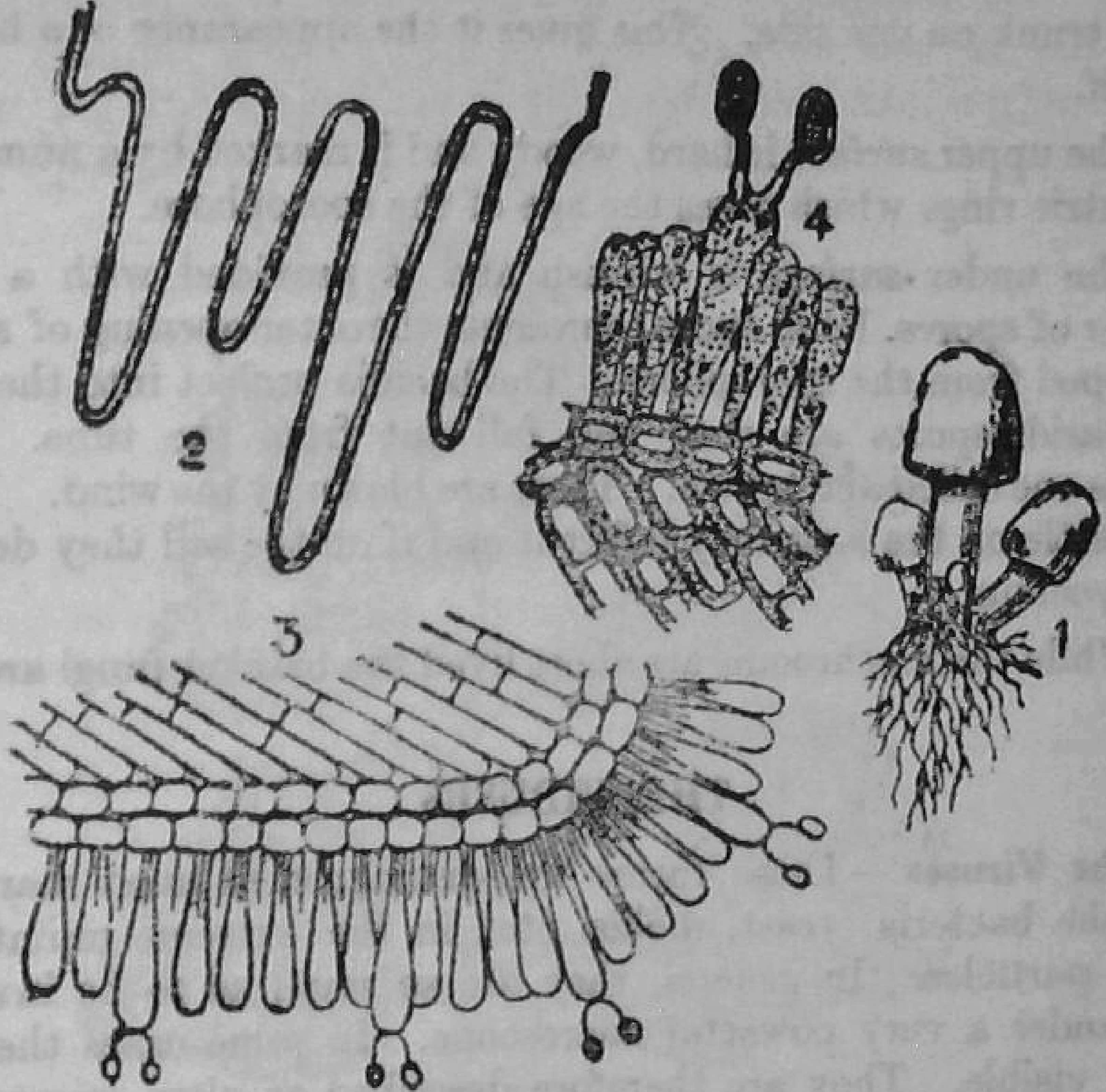

Fig. 290. The mushroom *Psalliota campestris*—Structure 1. young mushrooms ; 2. gill ; 3, a lamella with trama and spores ; 4. basidia and spores highly magnified.

Mushroom' because of the easiness with which it grows on paddy straw. One can cultivate this throughout the year in the plains in almost all the districts of the Madras province. It is not suited for cold latitudes and high elevations.

This differs from *Agaricus* in that at the base of the stalk there is a sheath called *volva* (*see* Fig. 290). This has no annulus and the spores are colorless.

The Bracket fungi.—These belong to the **Polyporaceae** (having many pores) and these are woody fungi.

Ganoderma lucidum.—The name bracket fungus is given because the fungus is attached to a side and resembles a shell.

The hyphae are present in the soil or inside the tissues of the affected plant. This is a root parasite and affects several perennial crops. The wilt disease of arecanut, root rot of coffee, tea or rubber and one kind of bleeding disease of coconut are caused by this fungus.

The hyphae are septate and very much branched. Afte invading the tissues, sporophores develop in the branches of ther affected trees. The sporophores horizontally disposed are attached

to the trunk on one side. This gives it the appearance of a bracket or shelf.

The upper surface is hard, woody and is marked by a number of concentric rings which gives the age of the sporophore.

The under surface is whitish and is provided with a small number of spores. Each spore represents the outer opening of a tube developed from the sporophore. The basidia project into the tube. The basidiospores are shed and fall out from the tube. Each spore is one celled and brown. These are blown by the wind. When they settle on the host they infect it and if on the soil they develop the mycelium.

While the mushrooms are short lived the bracket fungi are long lived.

THE VIRUSES

The Viruses.—These forms are distinguished most markedly from the bacteria, yeast, molds, etc., in the extreme minuteness of the particles. In general, they are so small as to be invisible even under a very powerful microscope. In some cases they are barely visible. They are therefore described as ultra microscopic and filtrable. The particles are small enough to pass through a filter in which the pores are sufficiently small to hold back the ordinary bacteria. The nature of the viruses has not been difinitely established. The first man to work on viruses was Ivanowsy. He found that it was possible to crush the tissue of the tobacco plant affected by the mosaic disease (virus disease), extract the juice, pass it through a filter with pores sufficiently fine to remove microscopically visible bacteria, inject this filtrate containing no visible particles, into a healthy plant, and regularly produce the disease. Later in 1892, Loeffer and Froesch succeeded in proving for an animal plague, foot-and-mouth disease, that the causal agent was also filtrable and ultramicroscopic.

There are two views. Some regard viruses as living things. Others hold that there is good reason to believe that the virus is not a living agent, and that it is to be grouped rather with organic catalysts such as enzymes.

It may well be that the viruses represent a type of living thing, with certain of the characteristics commonly associated with non living things.

Viruses are destroyed by high temperatures, as are bacteria. Some are resistant to drying while others are not. Here again they resemble the bacteria.

Classification of Viruses.—Viruses may be divided into three principal groups: those attacking animals, the *animal viruses*, those affecting plants, the *plant viruses*, and those attacking bacteria the *bacteriophages*.

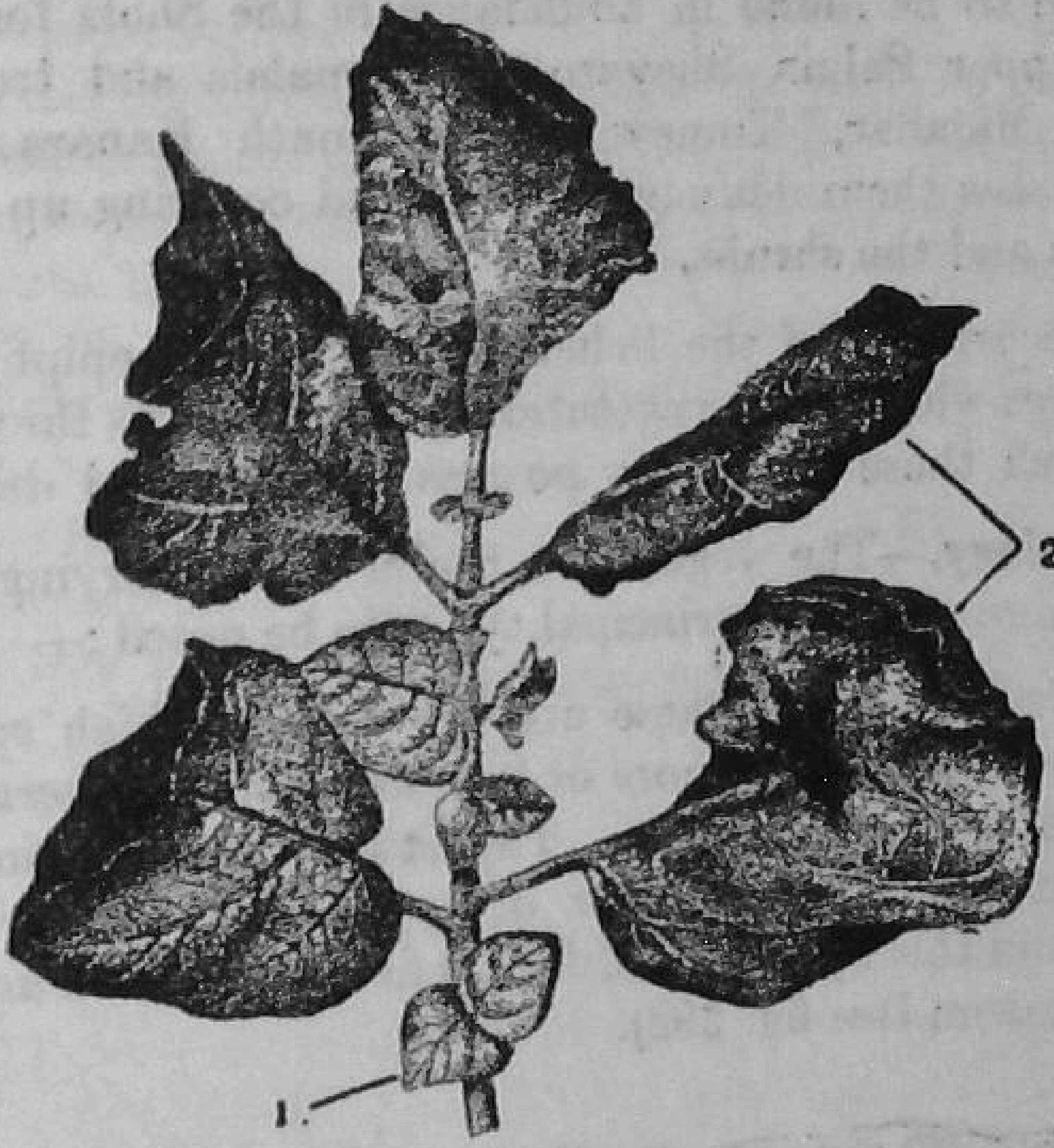

Fig. 291. Mosaic-Potato.

Symptoms produced by virus diseases are reduction in size of the affected plant, reduction of chlorophyll in affected leaf, deep and light green patches (such a patch is termed *mosaic*) accumulation of starch in leaves as the virus particle hinders the translocation of food material.

The following are some examples of virus diseases: Tobacc mosaic, spike disease of Sandal, mosaic of sugarcane, cardamom, *Dolichos lablab*, bunchy top of plantain, and clump disease of groundnut.

LICHENS

We have studied a few types of fungi and algae. Lichens are a class of thallophytes of lowly organisation that inhabit soil, rock, wood, trees, etc. The thallus is made up of two different organisms, namely, a fungus and an alga, so closely associated with each other that, for all appearances, they appear to be a single plant. The lichen is an instance of **Symbionts**, *i.e.*, two organisms living together and being of mutual help to each other. Such a condition is known as *Symbiosis*.

Lichens are cosmopolitan. They are found in all the regions of the world and in all climes. In our country one meets with them commonly in plains growing on the trunks of trees such as *Polyalthia longifolia*, Arecanut palm, etc., as round green patches. Lichens are to be found in abundance in the Shola forests of the Nilgiris, Upper Palnis, Shevaroys, Anamalais and tropical rain forests of Malabar, Tinnevelly and South Kanara. In these places one sees them densely clothing and covering up the trunks of the trees and the shrubs.

The occurrence of the lichens on rocks and epiphytically on barks of trees where other vegetation is absent shows the remarkable ability which these organisms possess to withstand drought.

Morphology.—The vegetative thallus is of varying form and colour. There are three principal types to be noted :—

(1) **Crustaceous.**—These are the lichens which spread over trees, rocks or soil with a more or less well *developed crust varying in* thickness, form, and colour. The thallus when sectioned shows generally an *upper cortical* layer of hyphae followed by a zone of *algal* layer and this by a mass of fungal filaments which are attached to the subtratum (*see* fig. 292).

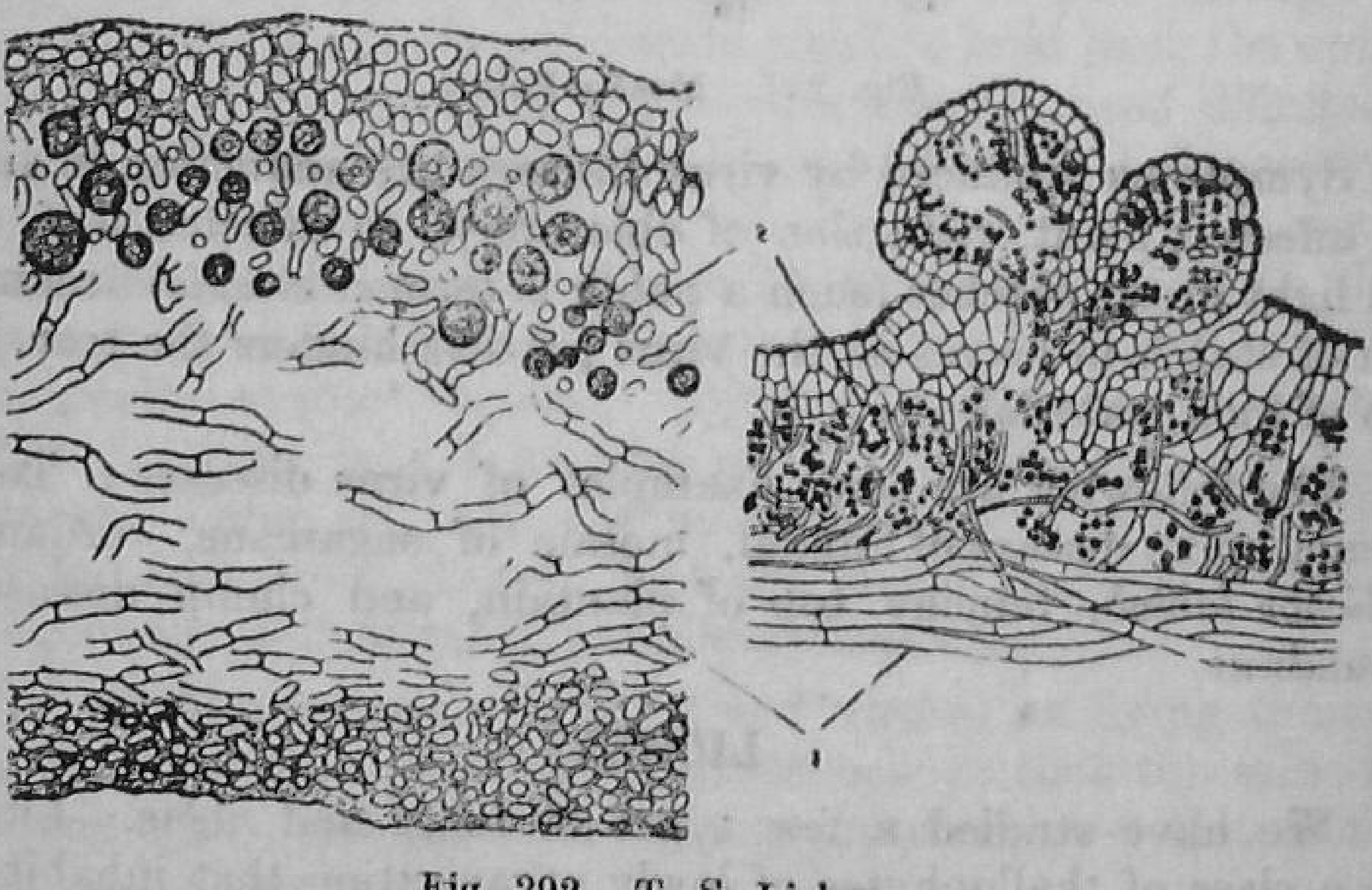

Fig. 292. T. S. Lichen

(2) **Foliose, Foliaceous or leafy lichens.**—As the name implies these are spreading *leaf like expansions* of one or many lobes firmly adhering to the support on which they grow. The structure of the thallus is more or less similar to that of the Crustaceous (Fig. 293).

(3) **Fruticose or shrubby lichens.**—These resemble somewhat the brown or the red algae in form. They are upright *branching* forms rising from a basal point and they are either cylindrical or strap shaped. The structure is radial and not dorsiventral as in the first and second types. There is a central pith of fungal hyphae, surrounded by a band of algae which in its turn has an outer cortex of fungal elements. There is considerable variety of form in this group ranging from forms with short, stiff, strap shaped lobes to those with long pendulous thread like strands (Fig. 294).

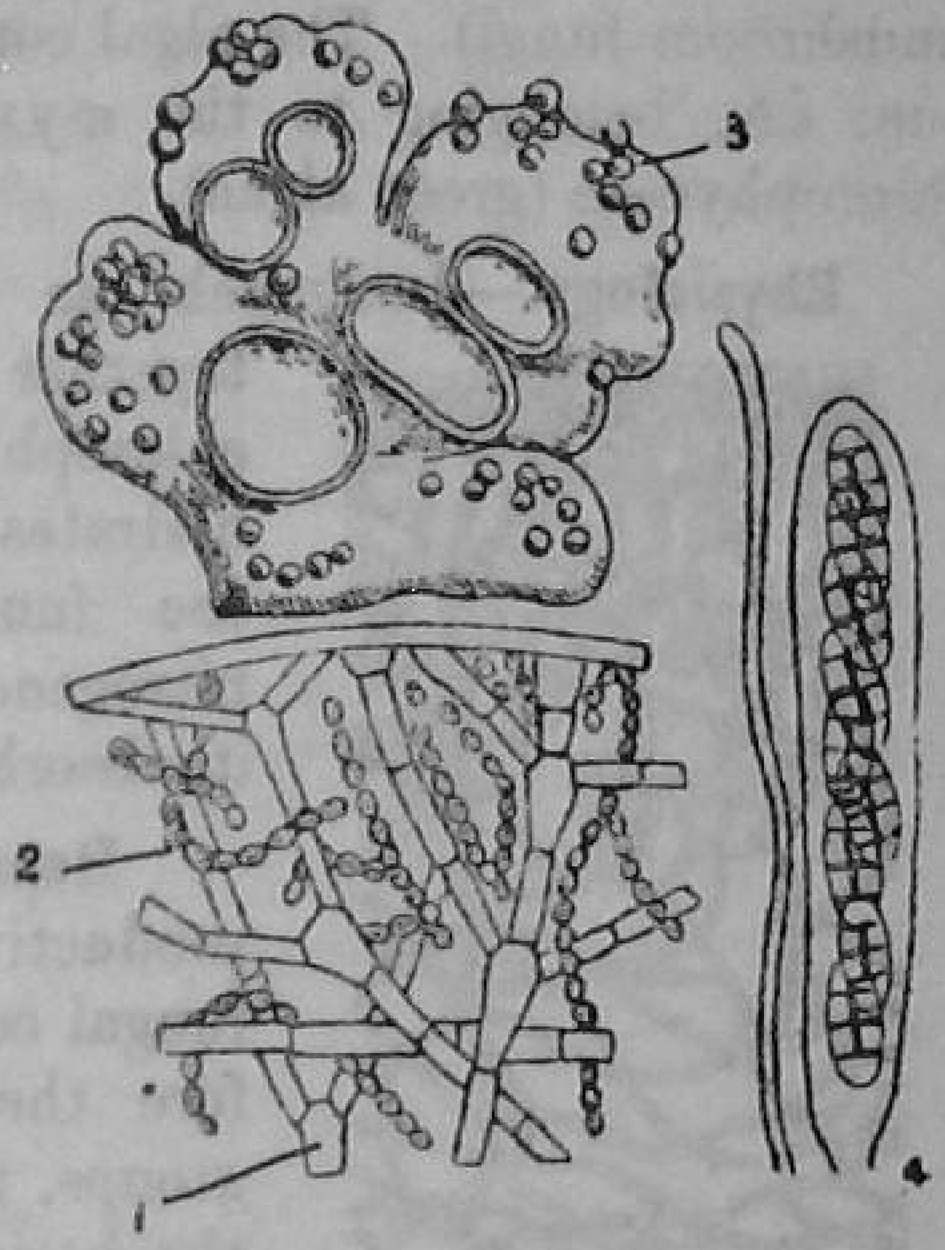

Fig. 293. Leafy Lichen

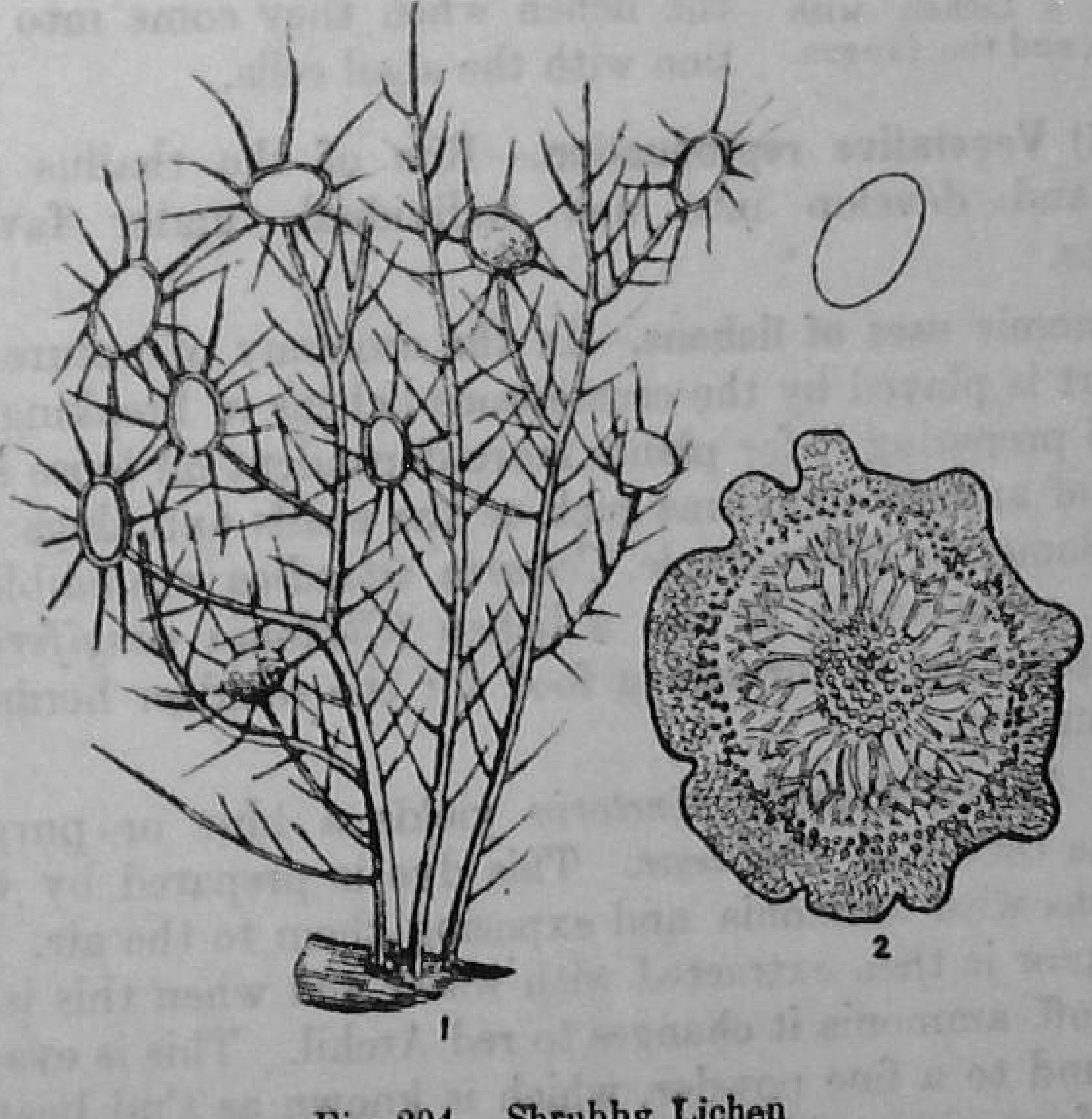

Fig. 294. Shrubby Lichen

Whatever may be the form of the lichen the structure is in fundamentals the same in all. A fungus and an alga go to make

up a lichen. The fungi of lichens belong to one of two groups, namely, the ascomycetes (yeast fungi) or the basidio-mycetes (mushroom fungi). The algal component of the lichen is a simple one, *i.e.*, belonging to the myxophyceae (blue green algae) or chlorophyceae (green algae).

Physiology.—Inasmuch as an alga and a fungus live together as a lichen, the alga with its chlorophyll manufactures the carbohydrates to feed itself and in return the fungus supplies the alga water, nitrogenous substances and salts which it absorbs from the substratum.

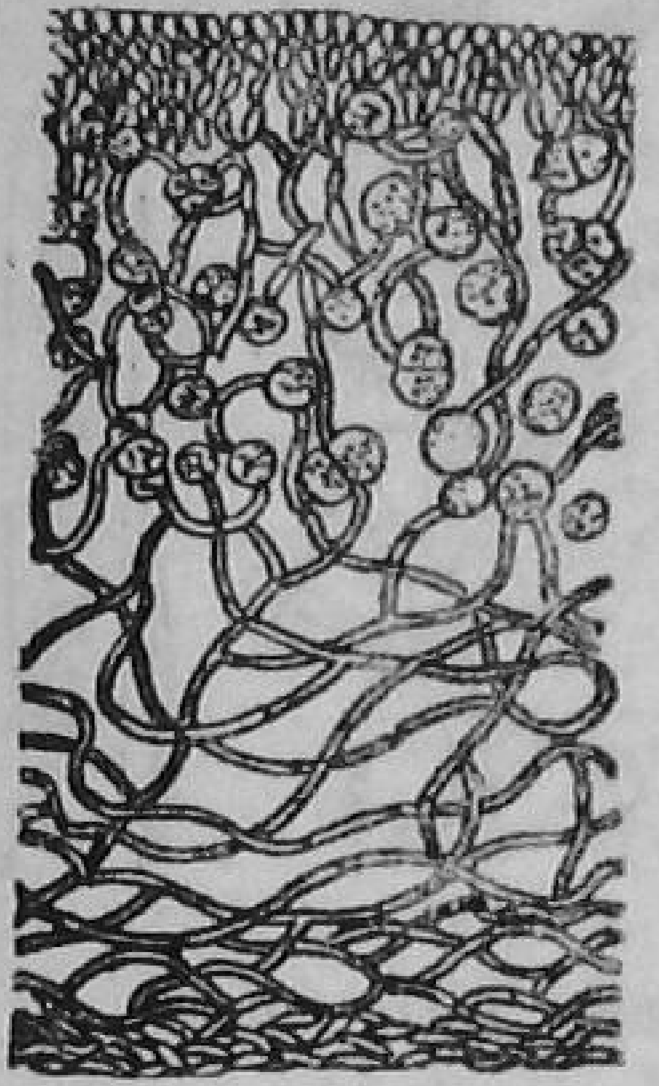

Fig. 295. A transverse section of a Lichen with the alga and the fungus.

Reproduction :—(1) **Sexual.**—The reproductive organs are formed by the fungal component of the lichen. Therefore the lichens are classified into two groups, namely (1) asco-lichens and (2) the basidiolichens. When the ascospore or the basidiospore germinates and the fungal hyphae are formed, these form the lichen when they come into association with the algal cells.

(2) **Vegetative reproduction.**—Bits of the thallus get detached and develop into new individuals under favourable conditions.

Economic uses of lichens.—In the economy of nature a very great part is played by the crustaceous lichens in breaking up the rock and preparing it for plants more dependent on loose soil. A number of animal organisms such as the snails and slugs feed on them. Some, as for example, *Cetraria islandica* are edible. The Reindeer moss which is also a lichen (*Cladonia rangiferia*) is of great importance in furnishing food for the reindeer herds in the Arctic Tundras.

The lichen *Roccella tinctoria* yields a blue or purple dye known as *Orchil* or *Cud-bear*. This dye is prepared by treating the lichens with ammonia and exposing them to the air. A blue archil liquor is then extracted with water and when this is heated to drive off ammonia it changes to red Archil. This is evaporated and ground to a fine powder, which is known as Cud bear. This dye was formerly used for silks and is at present utilised for staining wood and colouring wine. *Litmus* is obtained from the same lichens by a somewhat different process.

Oakmoss is the name given to the various lichens which play a very important part in the perfume industry. They are in main *Ramalina calicaris*, *Evernia furfuracea* and *E. prunastri*. These lichens contain oleo-resinous substances which are extracted by means of solvents. They not only have a heavy penetrating odour but have a high fixative value as well.

CHAPTER XXX

BRYOPHYTA

Liverworts and Mosses constitute the group **Bryophyta.** The number of species of **Bryophyta** are large, and they are widespread in all lands except where there is persistent drought. The green Thallophytes are essentially **aquatic** in their mode of life and none of them is found in sub-aerial vegetation. On the other hand, the **Bryophyta** are adapted for **sub-aerial** life on land. The structure of their vegetative organs is best fitted for life on land, although these plants have to depend for their fertilisation on external fluid water. This necessitated their growing in habitats where fluid water would be available, at least during the time of fertilisation. We have to consider the plants of this group as the most primitive forms of vegetation on land after Thallophyta.

Thallophyta and Bryophyta Compared.

Compared with **Thallophyta** these plants are higher in organisation. The sexual organs are extremely simple in the former, but not so in the latter. As Liverworts and Mosses live on land, the egg-cell which is a primordial cell has to be protected against the drying influence of the air. As a measure of protection the ovum or the egg-cell is retained within the tissues of the parent, and a special structure termed an **archegonium** is formed. It must be noted that the archegonium serves two purposes, namely, **protection** and **nutrition** of the ovum or the egg-cell. For the survival of the species this is very essential. The antheridia which produce the **spermatozoids** or (antherozoids) are also well protected and nutrition is ensured. The most striking feature of this group is that every species has in its life-cycle **two distinct generations, one alternating with the other.** The plant which is conspicuous is the sexual generation producing the sexual organs **archegonia** and **antheridia.** The sexual generation (the generation producing gametes) or the **gametophyte** is followed by the next generation, the spore-bearing generation called the **sporophyte.** In all Bryophytes, it is only the gametophyte that is capable of an independent existence, and the sporophyte is always dependent on the gametophyte for its nutrition. Another interesting fact is that the chromosomes in the nuclei of the sporophyte are twice as many as are found in the gametophyte. In other words, the gametophyte is the **haploid** generation and the sporophyte is the **diploid** generation. When fertilisation takes

place by the fusion of the nuclei of the sexual cells, the chromosomes become doubled, and the number becomes half by reduction division when the spores are formed.

The Bryophyta is comprised of the two classes. (1) Liverworts or **Hepaticae** and (2) Mosses or **Musci**; and they may be differentiated one from the other by the following characteristics :—

The Liverworts have in most species a dichotomously divided dorsiventral flat thallus, although a few species are foliaceous. In the sporophyte no columella is developed, and along with spores **elaters** are formed.

In the Mosses the plant is differentiated into a stem with leaves spirally arranged on it. No elaters are formed, but a columella is always formed in the sporophyte.

Liverworts (Hepaticae).

Liverworts usually flourish in beds of rivers, in ditches, on rocky ledges splashed by sprays of water, and in fact, in any place where there is enough moisture. A few species, however, live in dry habitats such as the bark of trees, on rocks or on the ground. They do not generally attract our attention very much as they flourish in nooks and corners. They are more common on the hills at higher elevations.

As an example of Liverworts we may study the cosmopolitan species *Marchantia polymorpha* since it is easily obtainable in all stages of development. The predominant generation or the gametophyte which is usually called the Liverwort has a plant body consisting of deeply lobed, dichotomously branched, dorsiventral green tissue. In the flat plate or the thallus there is a midrib like raised part. *Marchantia* forms large continuous patches covering the ground like a carpet, and the older portions of the plant die, leaving the younger parts to develop as independent plants.

The green dorsal surface of the thallus presents to the naked eye a number of rhombic areas, each of which being perforated by a central air-pore. The diamond shaped areas are really so many chambers, separated from one another by the lateral walls which determine the configuration of each chamber. The thallus is fixed to the soil by numerous unicellular **rhizoids**, arising from the midrib on the lower or ventral side. There are also two longitudinal rows of dark violet coloured scales on the ventral side each consisting of a single layer of cells springing from the thallus one on each side of the midrib. The scales are called **Amphigastria**.

An examination of the vertical section of the thallus reveals its complicated anatomical structure and dorsiventral character.

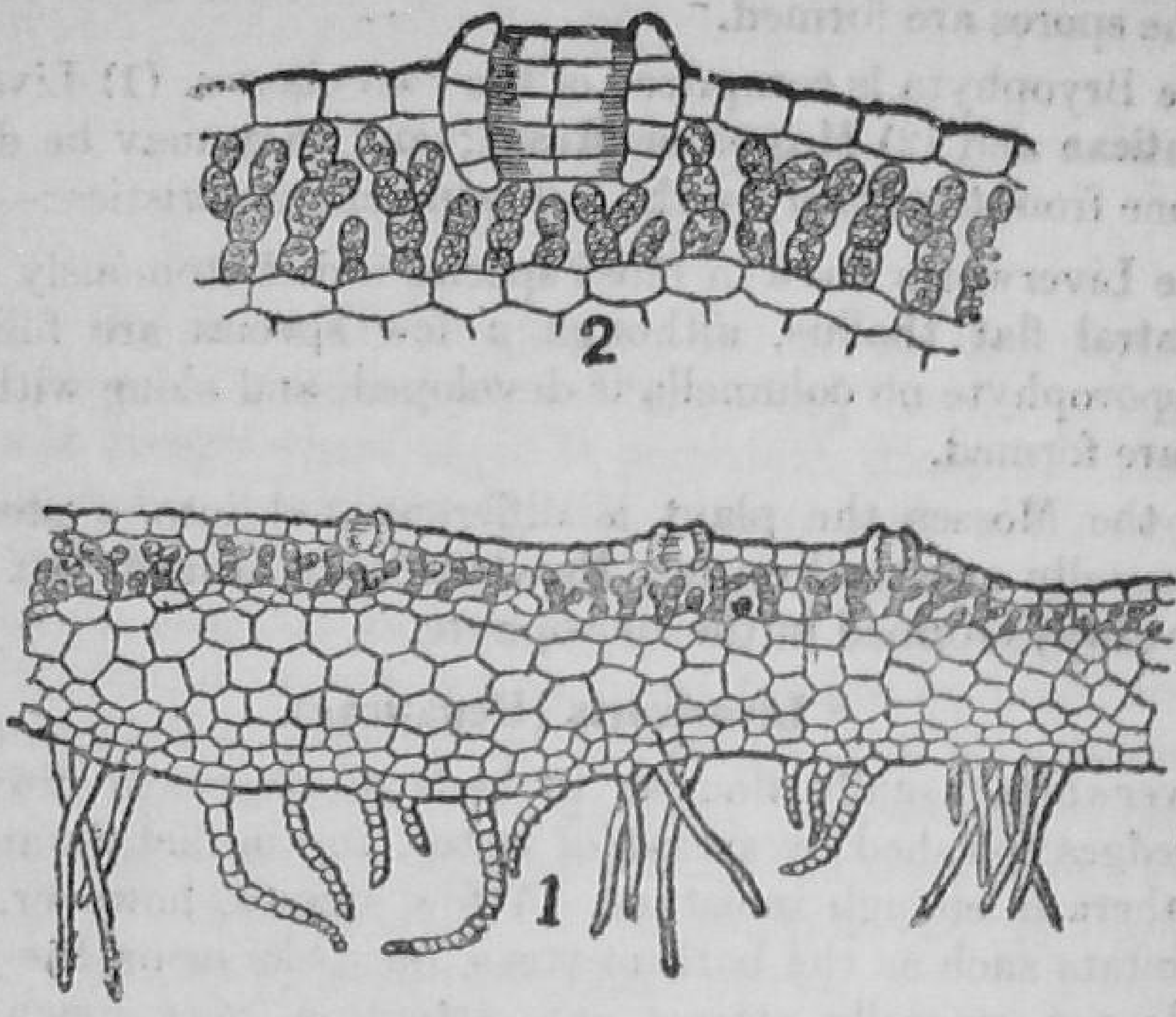

Fig. 296. Sections of the thallus *Marchantia polymorpha* showing the air chambers and the ventral portion bearing rhizoids and scales 1. slightly and 2, highly magnified.

The rhizoids which fix the thallus to the soil are unicellular tubes and they are of two sorts. Some of them are simple tubes with smooth walls while others have conical thickenings projecting into the cavity of the cell, the **pegged rhizoids.** The rhizoids are numerous and they form strands. Besides fixation, they absorb water and mineral salts although water is absorbed mostly by the plant body itself, as it is spread out and is in direct contact with the moist substratum.

The rhizoids and the scales spring from the outermost layer of the thallus on the lower side. This layer is the epidermal layer consisting of only one layer of cells. Above this we see a number of layers of large thin-walled parenchymatous cells forming the bulk of the ventral part of the thallus. These cells are usually colourless, although a few small chloroplasts may be found scattered in them here and there. Some cells, especially those towards the lower or ventral surface have reticulate markings on their cell walls. Cells containing mucilage or oil are found scattered amidst the cells of these layers. On the dorsal surface also there is an epidermal layer which is perforated here and there by air-pores, which are in the form of short canals bounded by tiers of cells. Each air-pore leads into a chamber, the epidermis forming

a roofing for the chamber. The chambers are separated from one another by distinct lateral walls. Each of the rhomboidal spaces seen on the dorsal surface corresponds to a chamber. From the floor of each of these air chambers several short branched rows of small cells full of chloroplasts arise. The development of the rows of chlorophyllous cells leads to an increase of the assimilating surface and these rows of cells are also placed in direct contact with the atmospheric air. These elaborate structural arrangements enable this Liverwort to carry on the work of photosynthesis as vigorously and as efficiently as the higher land plant.

Growth.—The thallus grows in length by the activity of a group of initial cells, formed from the apical cell at the growing point which is situated at the notched end of the thallus.

Reproduction.—Vegetative reproduction.—The gametophytes often multiply vegetatively by means of specialised bodies called **Gemmae** formed in cup-like outgrowths arising frequently on the dorsal surface in the region of the midrib. These cup-like structures with toothed margins called **Gemma-Cups** contain a large number of gemmae. These are flat, oval-shaped, green bodies with short stalk (Fig. 297). When mature, a gemma gets detached from its stalk, and then it develops into a thallus. As the number of gemmae formed in these cups is large, the Liverwort spreads to an enormous extent.

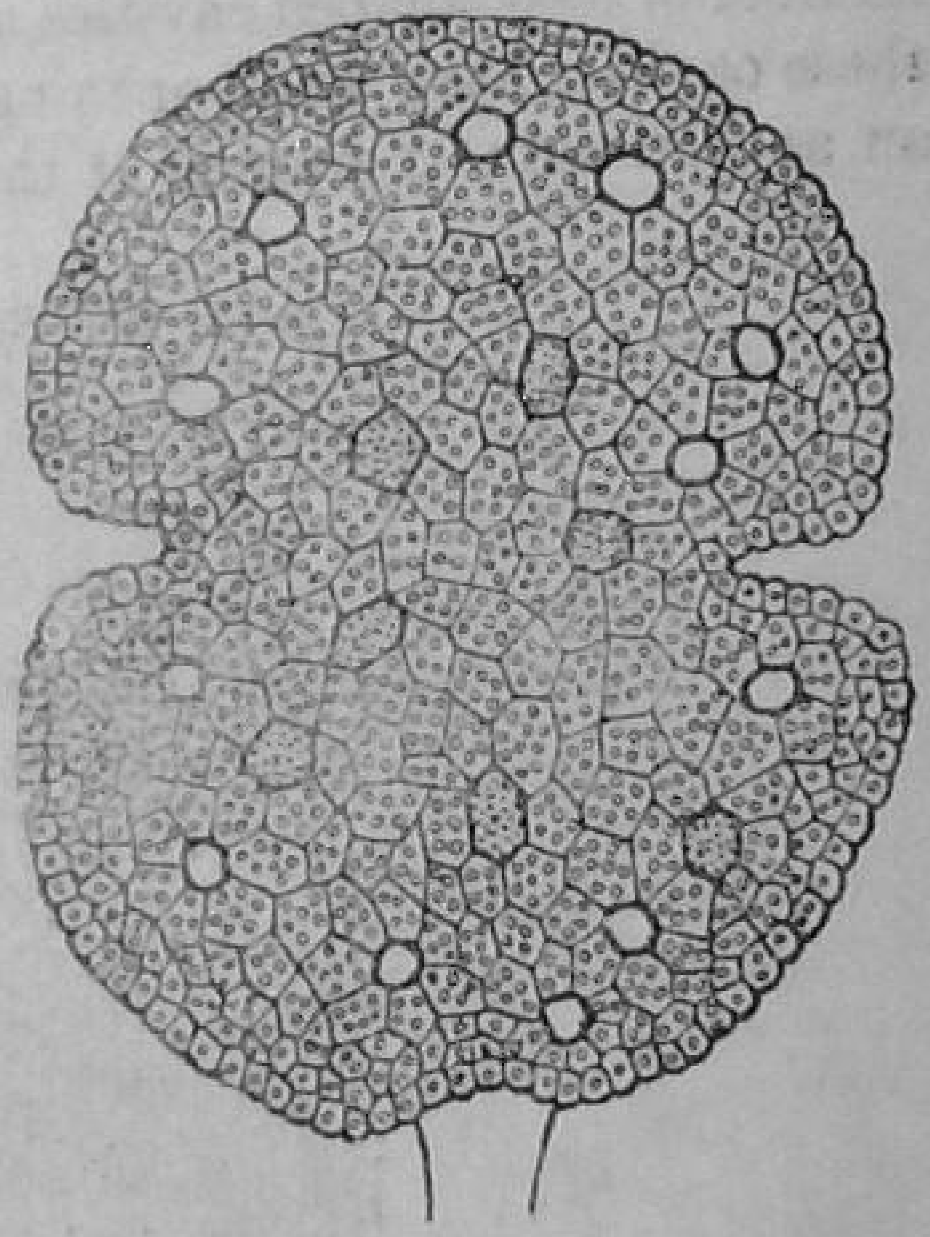

Fig. 297. Gemma.

Sexual reproduction.—The sexual organs, antheridia and archegonia are contained in the disc-like receptacles found at the ends of the erect special branches borne by the thallus. The branch bearing the antheridia is called an **Antheridiophore** and the one the archegonia, an **Archegoniophore.** This Liverwort being dioecious, the sexual organs are not found in the same plant, but occur in different plants. The stalks of the branches and the discs are only thalli that have become erect the lower portion being contracted and the upper part expanded. The presence

of rhizoids and scales in the grooves of the stalk and on the lower side of the disc shows their real nature. The internal structure of the disc is exactly similar to that of the thallus. The chambers and the air-pores are found on the upper surfaces of both the male and female receptacles.

Fig. 298. Male and female plants of *Marchantia polynorpha.*

The male receptacle is somewhat rounded with its free margin being slightly lobed. On the dorsal or upper side a number of flask-shaped cavities are found in radiating furrows. All these cavities have small openings **ostioles** on the upper surface and an antheridium is formed at the bottom of each of these cavities.

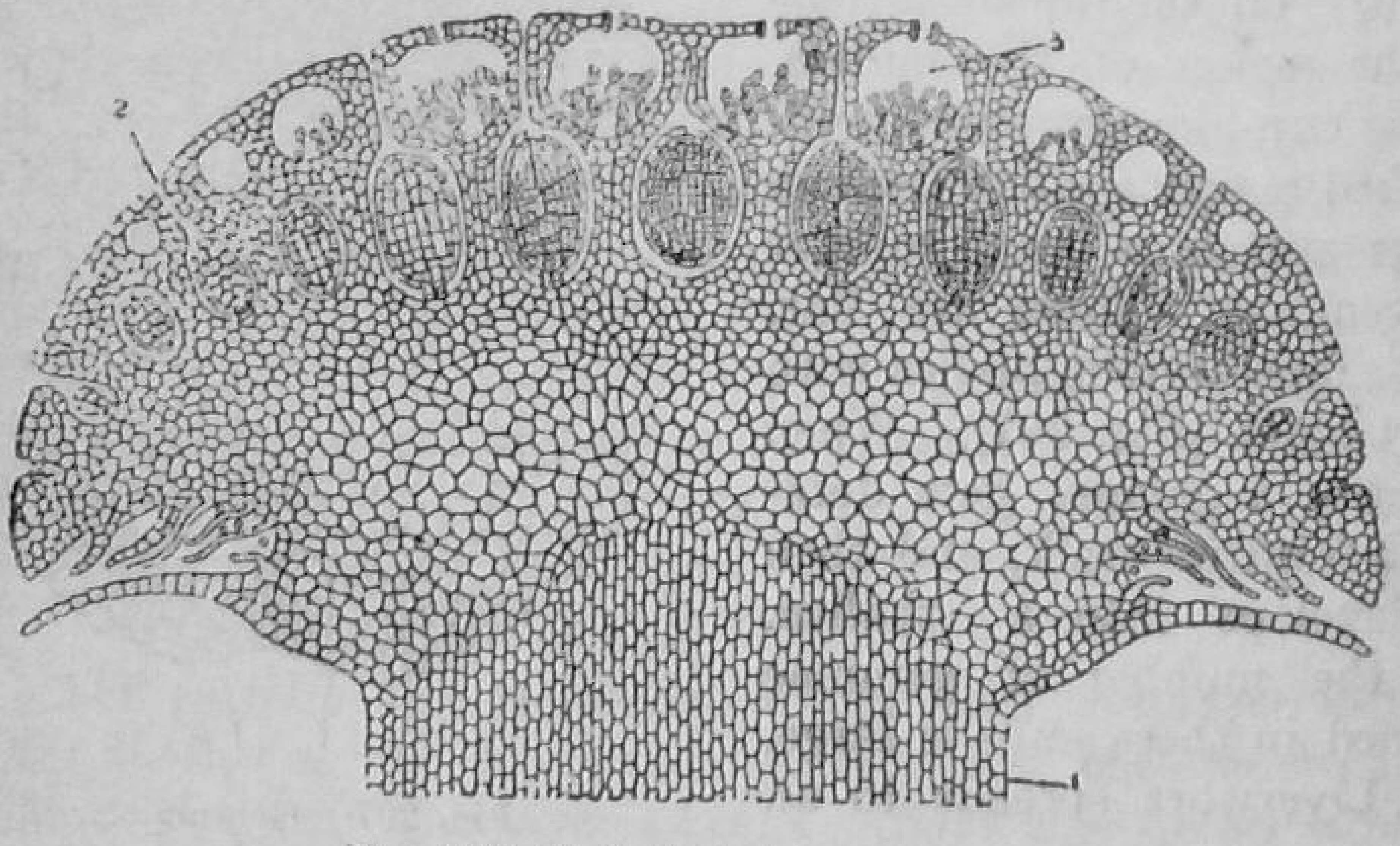

Fig. 299. T. S. Showing antheridia.

The antheridia lying close to the centre of the disc are older than those at the periphery. An antheridium is a short-stalked oval body consisting of a wall of single layer of cells enclosing a large number of mother-cells of **spermatozoids.**

The female receptacle is a disc with nine or eleven radially disposed finger-like processes. The archegonia are found in two radial rows between the rays, these rows being surrounded by a

sheath. The archegonia are formed at first on the upper surface of the disc, but later by growth and distortion they occupy the lower side. An archegonium is a short-stalked flask-shaped body,

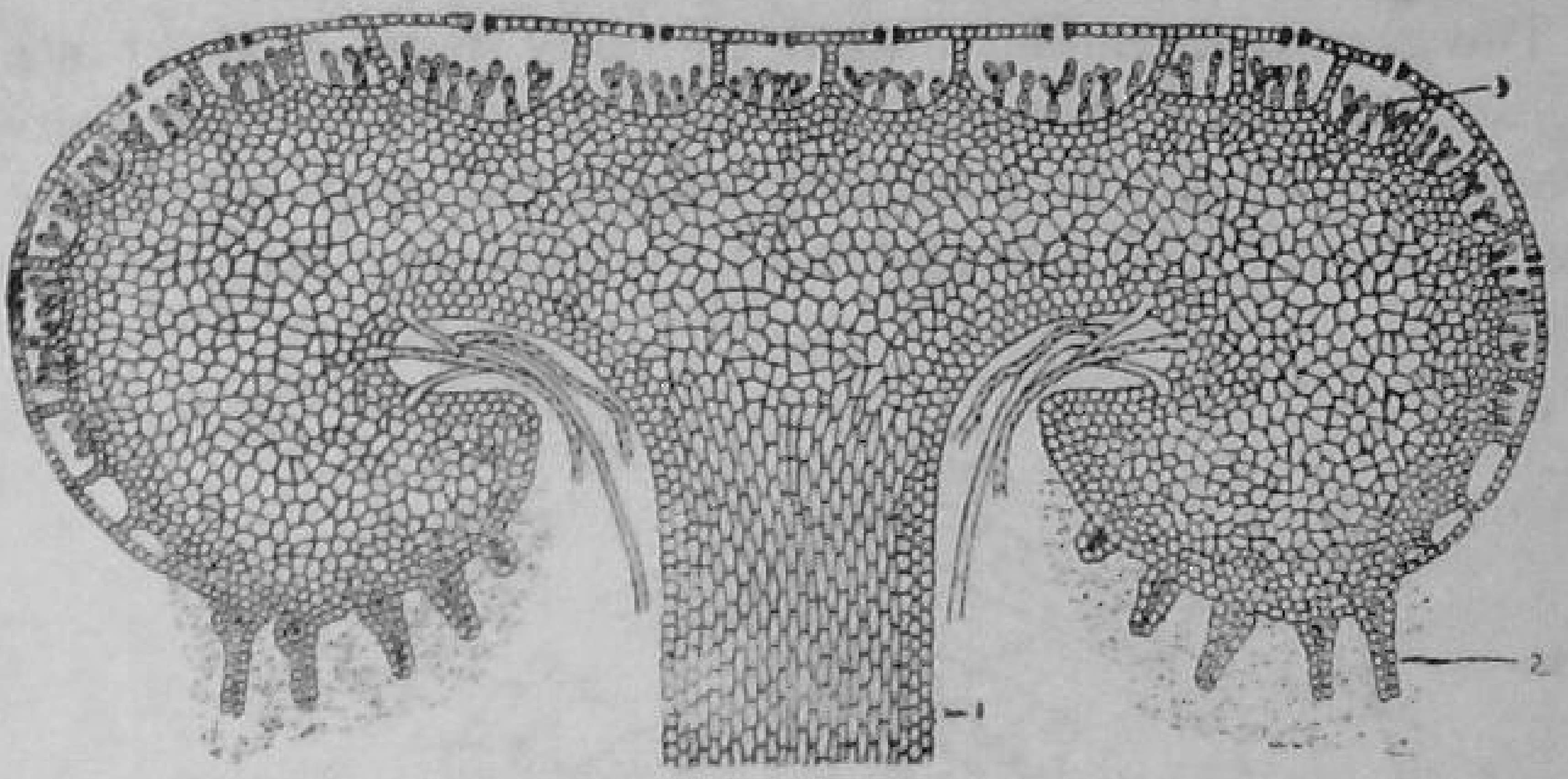

Fig. 300. Section through female receptacle.

consisting of a dilated lower portion or the **Venter** and a very long **Neck.** The wall of the venter is composed of a single layer of cells, closed at the apex when young. The **Oosphere** (egg cell) and the **Ventral canal cells** are in the venter and the neck is occupied by the **Neck-Canal-Cells.** When the archegonium matures the ventral canal-cell and the neck canal cells change into mucilage which escapes at the apex forcing apart the cells at the apex which formed the **Lid.**

Fertilisation takes place only during the rain. It is only then that the spermatozoids escape and remain at the mounts of the cavities containing the antheridia. The liquid on the male discs get splashed to the female receptacles by rain drops. The spermatozoids that are thus carried to the surface of the female receptacles are attracted towards the mouth of the archegonia by the mucilage extruded at the top of the neck. The spermatozoids are attracted by protein substances contained in the mucilage. So these pass down the canal and one of them fuses with the oosphere. The zygote develops into an embryo which later on grows into the **sporogonium** or the **asexual generation.** In all the Liverworts

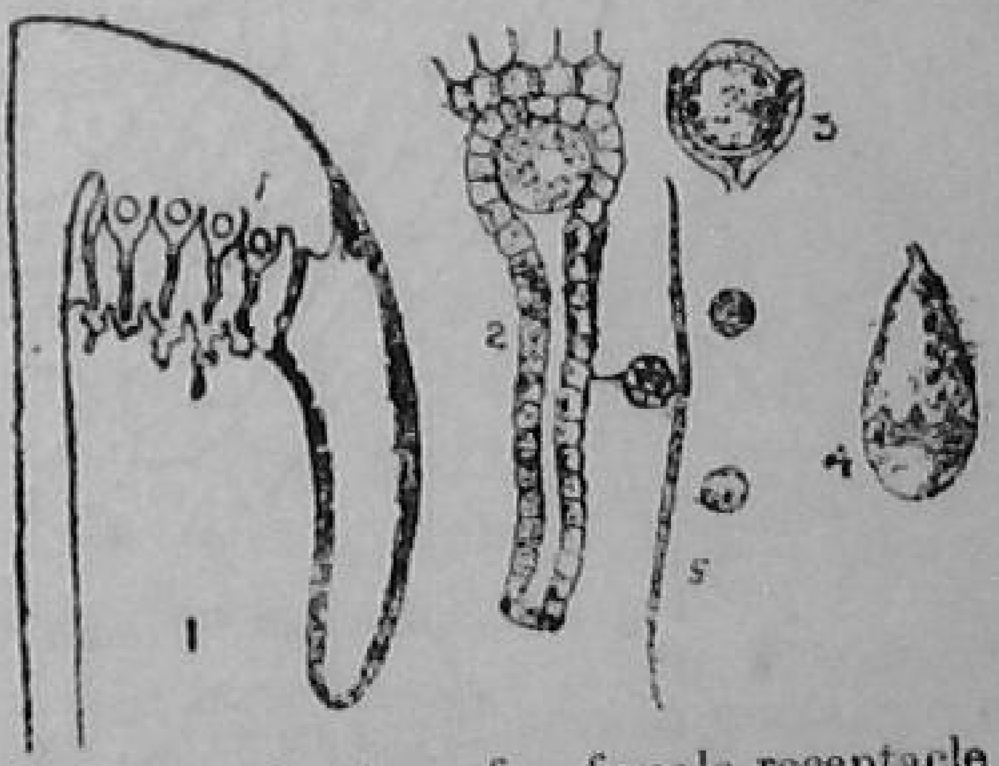

Fig. 301. Section of a female receptacle of *Merchantia polymorpha* showing archegonia and sporogonia, 1. Vertical section of an archegoniophore, 2. an archegonium in section; 3 & 4 sporogonia, 5. spores and elaters.

the sporogonium remains attached to the sexual generation throughout its life. So it gets all the materials needed for its growth and development from the gametophyte.

The sporogonium is a rounded body with a short stalk at first, and the stalk elongates with the growth of this body. In a receptacle which is mature, a number of sporogonia are seen between the rays. The **capsule** of the sporogonium has a wall

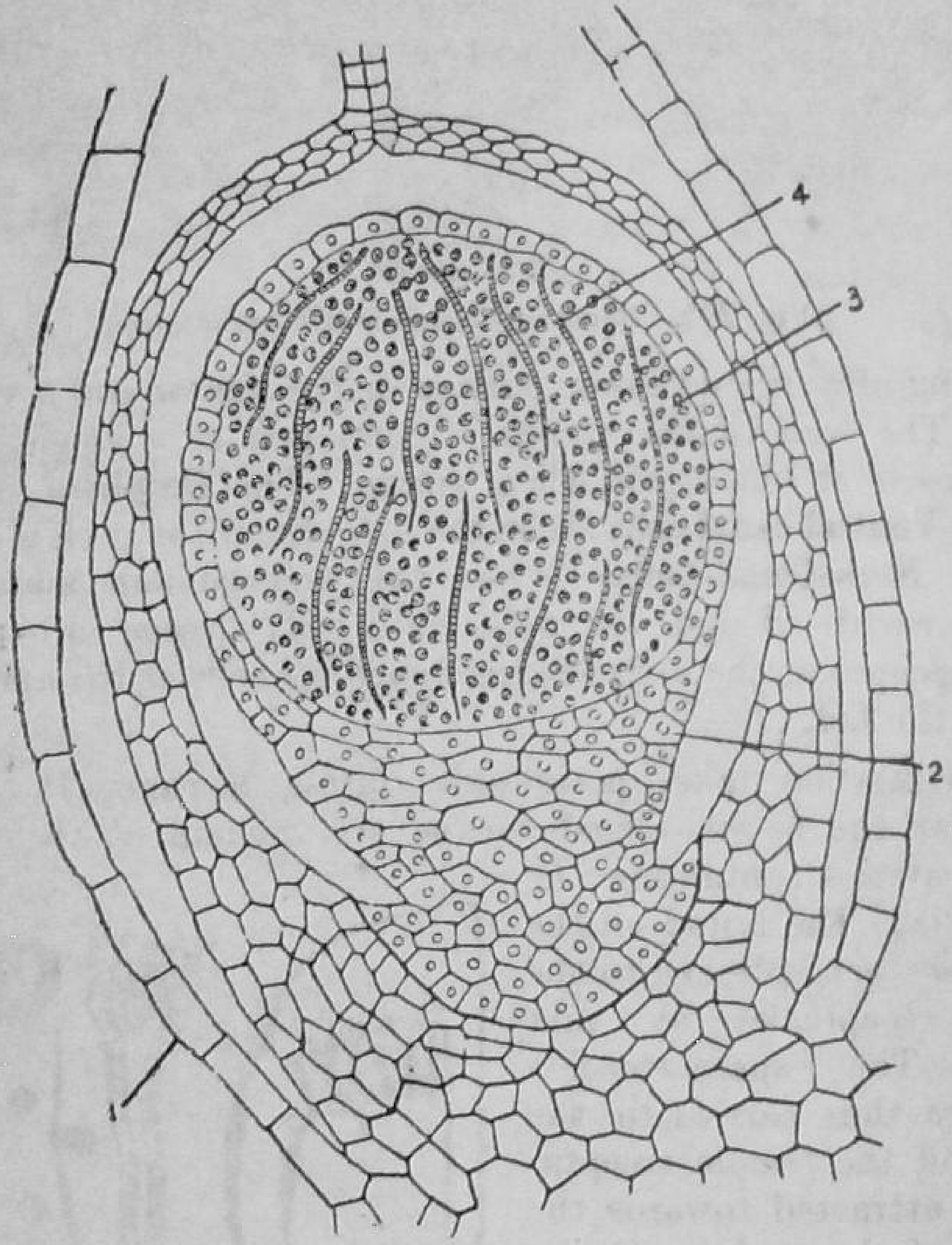

Fig. 302. Section through Sporogonium of *Marchantia.*

consisting of one layer of cells, except at the apex, where it consists of two layers of cells. The capsules burst open at the apex exposing the spores. Within the sporogonium in addition to the spores, elongated fibrelike cells having spiral thickenings are formed. These are called **elaters** and they are hygroscopic. The elaters help in the dispersal of spores.

Germination of Spore.—The spore germinates and a short tube grows out from the spore and this grows and eventually forms a

disc, from which the Liverwort develops as a lateral growth. The green tube and the disc together constitute the **protonema** or **pro-embryo.**

The life history of *Marchantia polymorpha* is thus seen to consist of two distinct generations, namely, the gametophyte and the sporophyte and these regularly alternate. The sporophyte gives rise to the gametophyte and the gametophyte produces the sporophyte. This phenomenon is described as the "**Alternation of generations.**" (Fig. 303.)

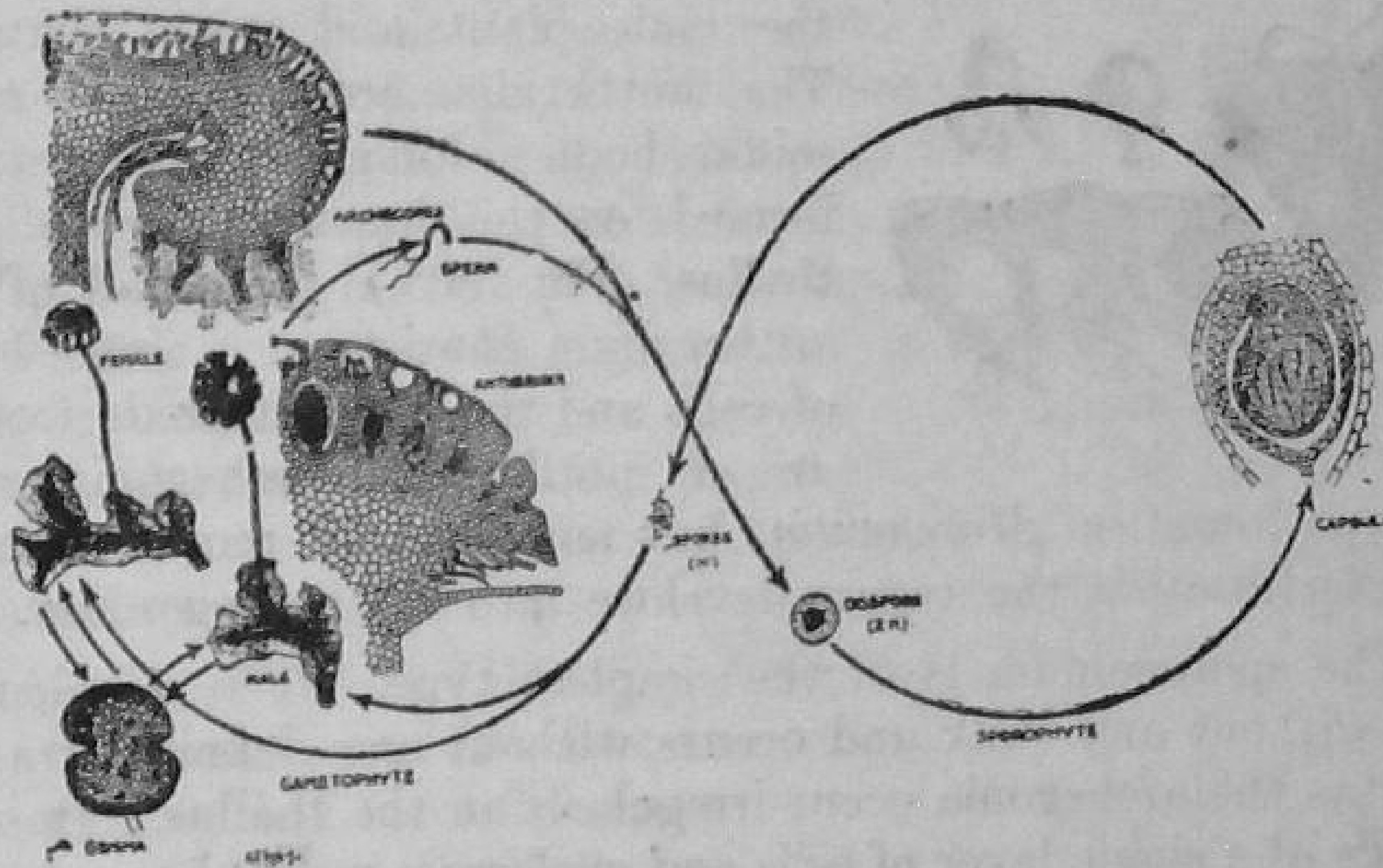

Fig. 303. Life cycle of *Marchantia.*

Another Liverwort fairly common in the plains, namely *Riccia sanguinea*, Kash., may be taken as another type of this group of plants. (Fig. 304.) It grows on damp or marshy soils, its thallus forming small rosettes. The thallus consists of short, ribbon-shaped, dichotomously lobed or cleft branch radiating from the centre. The plants retain their rosette shape so long as they are isolated, but when they grow together the shape becomes irregular on account of the overlapping of the branches. The thallus is fixed to the soil by means of simple unicellular rhizoids springing from the underside.

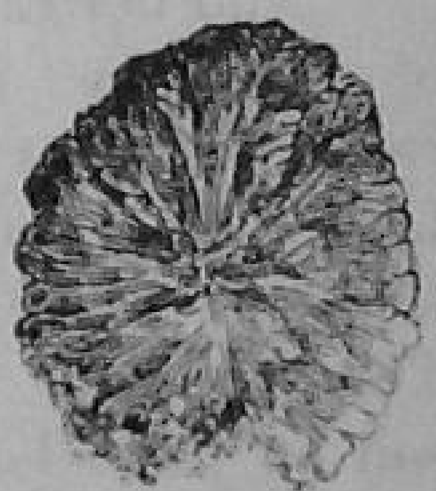

Fig. 304. Riccia sanguinea, Kosh., an entire plant.

The structure of the thallus is very simple. The dorsal side possesses air-chambers with openings towards the outside. But these openings are different from those of *Marchantia.* Although the air spaces are separated by short partition walls

consisting of cells possessing chloroplasts, they are not so conspicuously marked externally as in *Marchantia*. The ventral portion consists of uniform parenchyma. The rhizoids are unicellular and they arise from the lower epidermal cells.

This plant also is diœcious like *Marchantia*. The ventral portion consists of uniform parenchyma. The rhizoids are unicellular and they arise from the lower epidermal cells. The male plants are usually smaller than the female plants, and though mostly green, occasionally are of red colour. The female plants are always green in colour, somewhat larger than the male plant and more compact. The antheridia are somewhat ellipsoidal bodies found in the cavities formed on the dorsal surface of the thallus. (Fig. 305.) The wall of the antheridium consists of a single layer of cells and the spermatozoids formed are all motile. The archegonia are of the type found in *Marchantia*, but smaller and more compact. After fertilisation the zygote develops into the sporogonium.

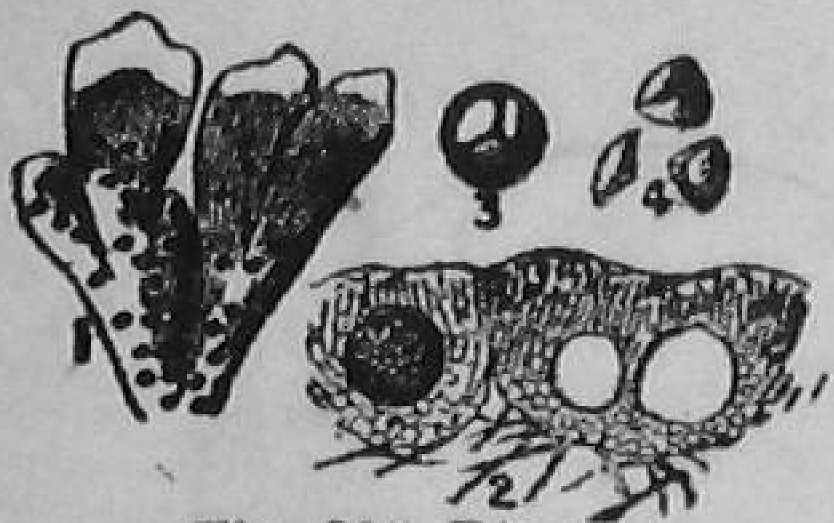
Fig. 305. Riccia.

The sporogonium is of the simplest type. It is a spherical body without any stalk and occurs without any definite arrangement, as the archegonia occur irregularly in the thallus. Its wall consists of a single layer of cells and encloses a mass of terrahedral spores. No elaters are formed in these sporocarps.

As in other Liverworts, the spores escape by the rupture and disintegration of the venter and the surrounding cells of the thallus.

Another Liverwort, *Anthoceros*, representing an isolated group of *Hepaticae* may also be examined. (Fig 306.) This genus is really one of a primitive order of *Bryophyta*. The gametophyte forms small green irregular patches on the ground amidst grass, soon after the rains. It is common in Madras in tank beds. The thallus is simple, irregularly disc-shaped and is fixed to the soil by rhizoids.

The structure of the thallus is uniform, and large chloroplasts occur singly in the cells of the thallus. Clefts occur generally on the lower surface, and these lead to mucilage cavities, often invaded by *Nostoc*-colonies.

Plants of the species *Anthoceros Laevis* are monoecious. The antheridia and archegonia are developed on the thallus of the same plant without any definite arrangement. The antheridia occur singly or in groups of two to four, entirely sunk

in the thallus and in perfectly closed cavities. When these are mature, the cells forming the covering get ruptured, and they open at their apices and discharge their spermatozoids. The archegonia also are found immersed in the tissue of the thallus and even when they are fully formed their necks do not project above the surface of the thallus.

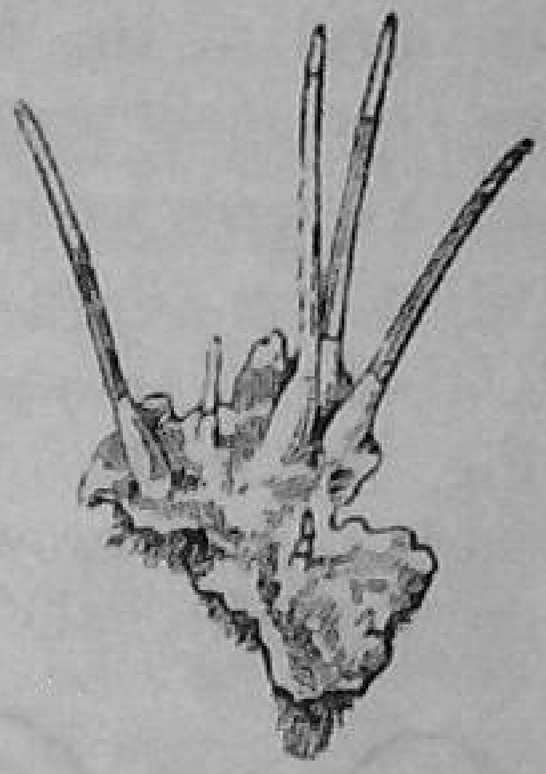

Fig.306. Antheceros Laevis.

After fertilisation the sporocarp is formed within the thallus and this emerges out rupturing the overlying membrane of cells by elongation. This membrane forms a sheath at the base of the sporogonium. When fully formed, the sporogonium is a narrow elongated structure without a stalk and consists of a swollen foot and a long pod-shaped capsule. The capsule has a very slender **columella,** and the capsule splits gradually from above downwards and longitudinally into two valves. Along with the spores curiously shaped multicellular elaters occur.

The sporocarp has stomata and chloroplasts. So the sporophyte, represented by the sporocarp is capable of making its own food though it is dependent on the gametophyte for water and salts.

In all the Liverworts there is a distinct alteration of generations the gametophyte invariably being the more conspicuous generation and the sporophyte always appearing as a dependant of the gametophyte.

MOSSES (MUSCI)

Mosses are more highly organised than Liverworts, especially in their sporophytes. The number of species amongst Mosses is very large and they are also widely distributed. They flourish in all sorts of places such as rocks, tree-trunks, logs, tops and

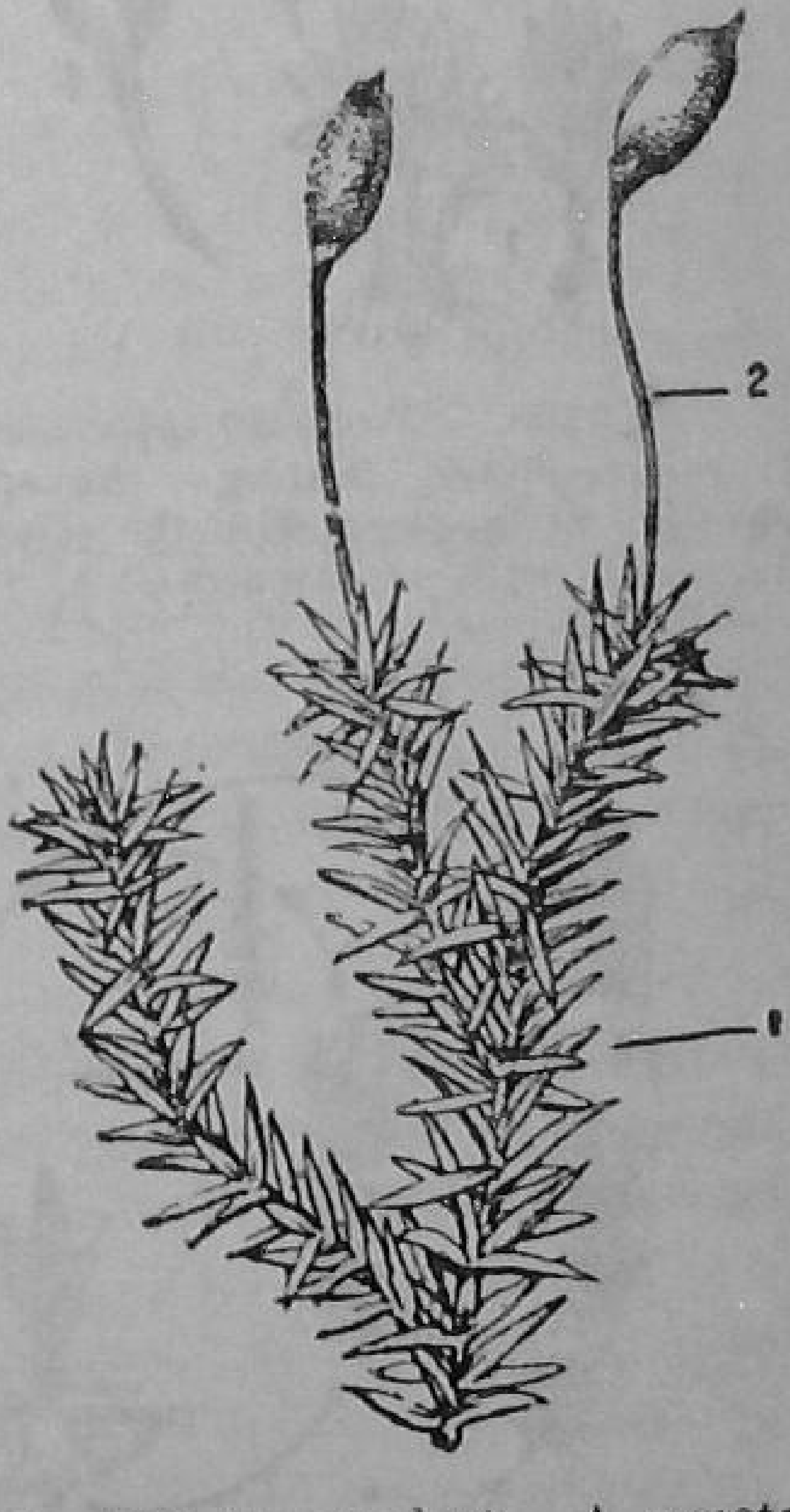

Fig. 307. A moss plant. A gametophyte bearing the Sporophyte.

sides of walls and on the soil. After monsoon rains almost everywhere patches of Mosses appear. They are distributed from the sea level to the tops of mountains of great elevations. They are cosmopolitan and found all over the world.

As types we may study species of *Funaria* and *Pogonatum.*

The Moss *Funaria* grows commonly in tufts on the surface of the ground, and it is sure to be found in many places. (Fig. 308). The conspicuous Moss-plant is the gametophyte and it usually grows to a height of about half an inch. In it we can distinguish the stem and the leaves borne by the stem in a spiral manner. It must here be remarked that the leaves of Mosses cannot be homologous with the leaves of Angiosperms or Ferns, as in the latter, the leaves belong to the sporophyte generation. At the base of the stem of the Moss-plant a large number of fine rhizoids are found fixing it to the soil. Branching of the shoot is very rare, and the later branches arise not from the axils of leaves, but from below them.

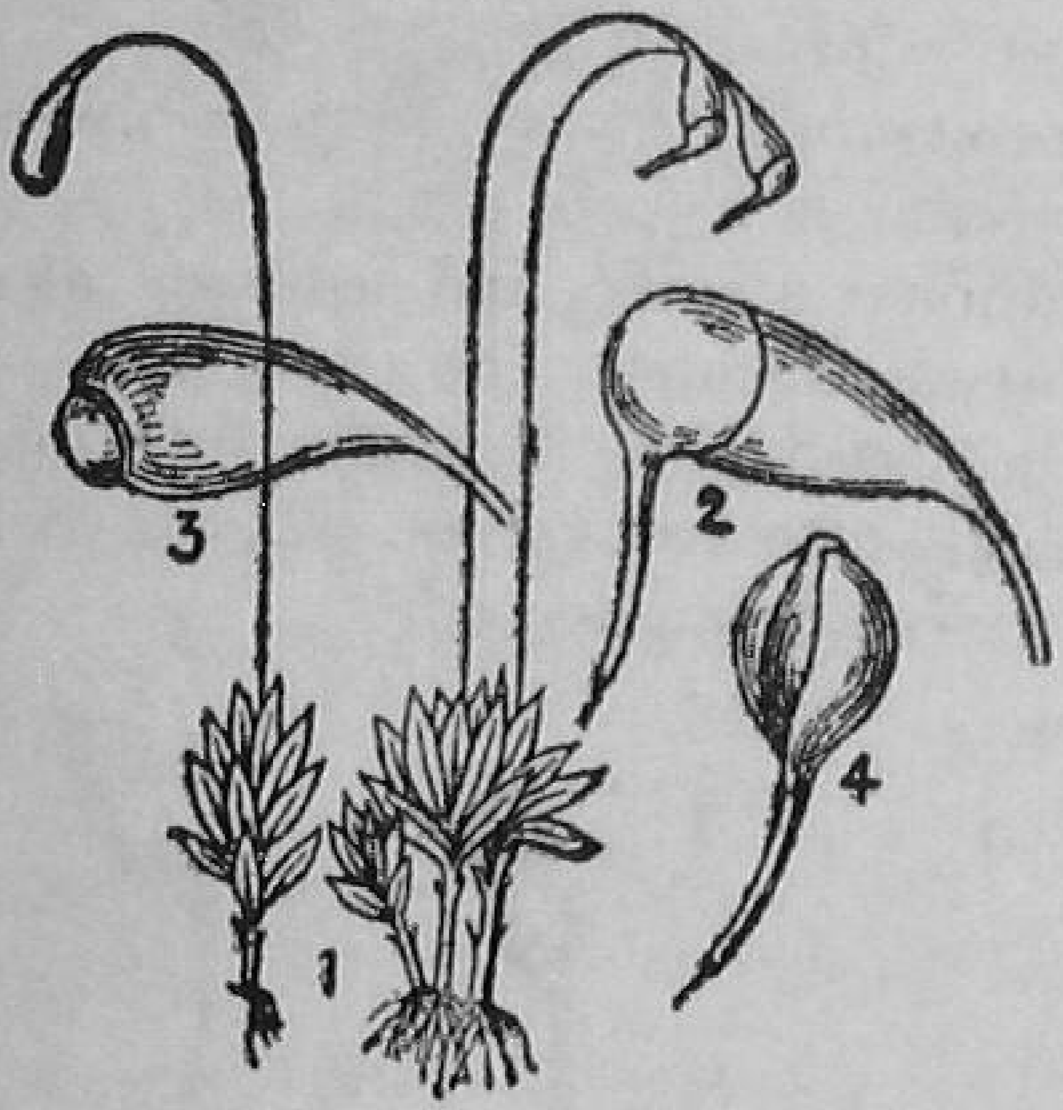

Fig. 308. *Funaria hygromapica* 1. gametophytes bearing the sporophytes. 2. the theca with the calyptra. 3. capsule without calyptra. 4. Inner view of calyptra.

Leaves of *Funaria* are simple, ovate, and sessile with entire margins. Every leaf consists of a single layer of

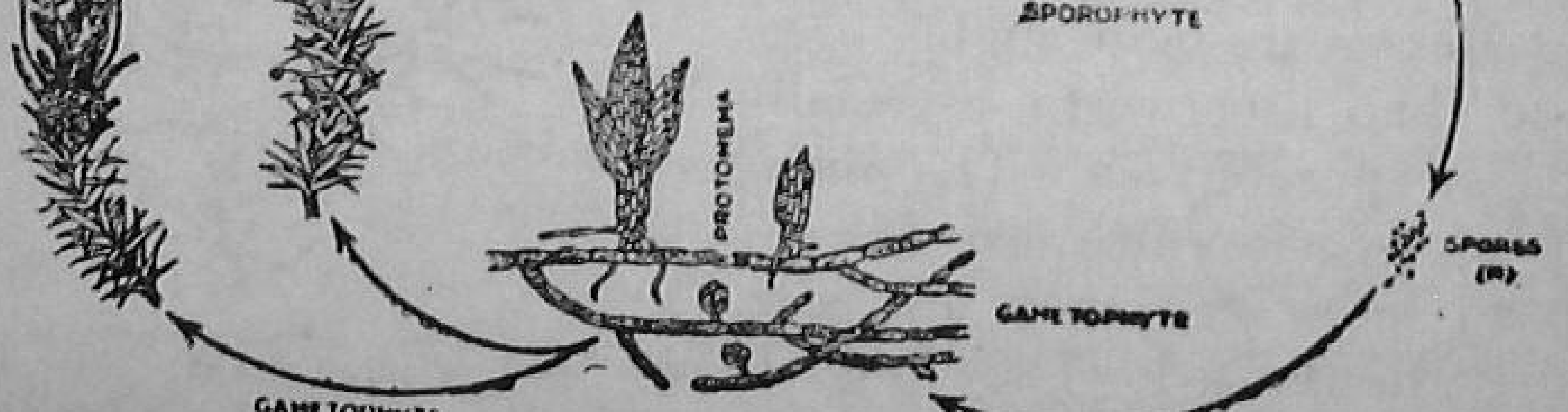

Fig. 309. Life cycle of a moss plant.

cells except at the midrib where there are more layers of cells. All the cells contain chloroplasts. Stomata are not found either on the leaves or on the stem.

The stem consists of a central core of elongated thin walled cells surrounded by a many-layered cortex. Chloroplasts are found in the peripheral layers of cells in the cortex, though not in the inner layers. The growing point of the stem is terminated by a single apical cell, from which cells are derived by division.

Reproduction, Sexual.—The sexual organs, antheridia and archegonia, are developed on the same plant, and they occur in groups at the ends of shoots. The ends of stems bearing antheridia become conspicuous, since the leaves near the antheridia are close-set and spread out so as to form rosette-like structures. These stair-like structures consisting of leaves, antheridia and special hairs called **paraphyses** are often termed "male flowers.' Though archegonia also are grouped at the free ends and covered by leaves, they are not conspicuous in any way. They are just like the leafy buds appearing at the free ends of shoots.

The **antheridium** is a club-shaped body just visible to the naked eye. It is really a sac with a stalk, containing spermatozoids inside still enclosed in cysts if ripe, or mother-cells of the spermatozoids if unripe. The wall of the antheridium consists of one layer of cells containing chloroplasts when young, but these bodies turn yellow or red, at the maturity of the antheridium.

The **archegonia** are similar to those of the Liverworts, but with longer stalks and venter with two layers of cells. The neck-canal cells become disorganised into mucilage and this mucilage is found at the free end of the neck of the archegonium. Usually this substance contains canesugar which is said to attract the spermatozoids. As in Liverworts, in Mosses also the spermatozoids are biciliated bodies.

After fertilisation the egg cell grows into a small elongated structure whose lower end or the foot becomes sunk in the tissue of the gametophyte. Then with the growth of this embryo the venter of the archegonium also grows. Very soon the embryo begins to elongate into a long stalk-like body carrying with it the upper portion of the archegonium which gets ruptured at the middle of the venter. Towards the free end of this rapidly growing embryo, there appears a capsule hidden by the upper torn portion of the archegonium now termed **calyptra** appearing like a cap.

SPOROPHYTE

A ripe sporogonium (Fig. 310, 311) consists of a long stalk or the **seta** bearing the **capsule, urn** or the **spore-sac** usually covered by the hood or **calyptra.** In *Funaria hygrometrica* the seta is bent at the top and the calyptra is oblique and tipped with a process. The capsule, urn or the **theca** is oblique and pyriform. The upper portion of the theca is differentiated into an oblique lid, and just below the lip or **operculum** there is a ring called **annulus** consisting of cuticularised epidermal cells. By the rupture of this ring the operculum is thrown off, and then at the top of the capsule we find a kind of membrane termed the **peristome** closing its mouth. (Fig. 310.) The peristome consists of two series of yellow triangular teeth, sixteen in each series. The basal portion of the capsule is solid consisting of parenchymatous cells and is called the **apophysis.** The epidermis covering the apophysis has stomata and the cortex consists of cells containing chloroplasts.

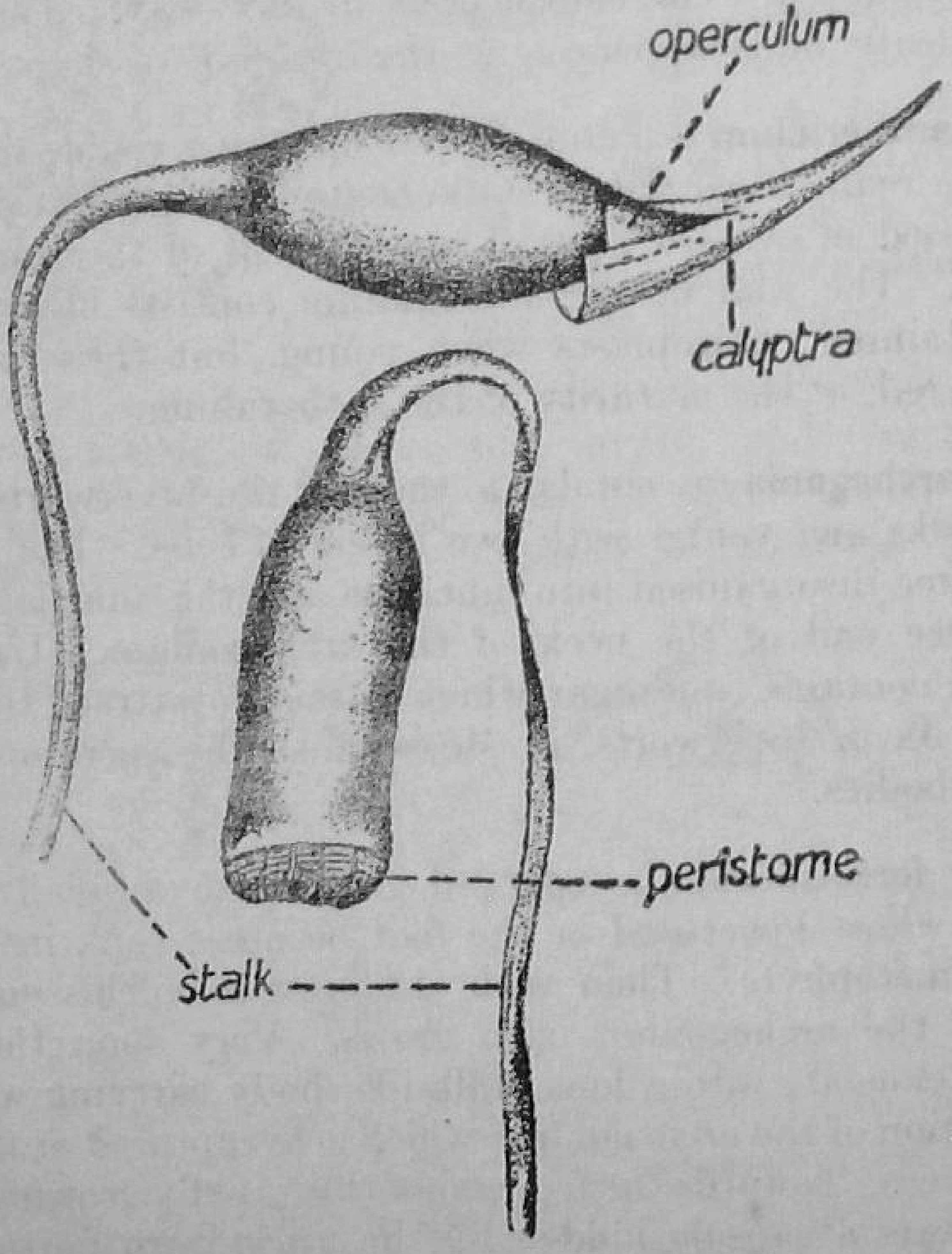

Fig. 310. Sporogonium.

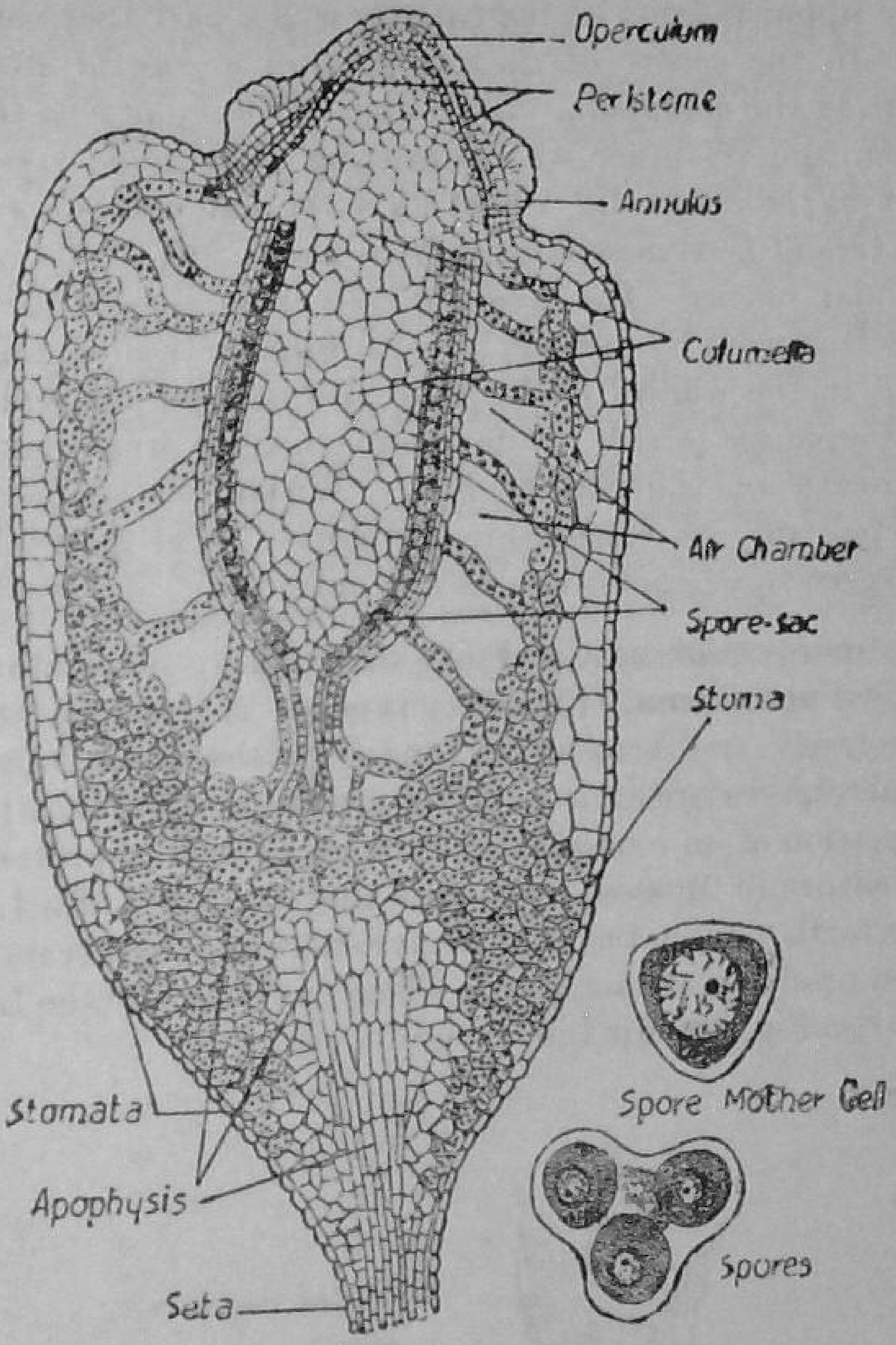

Fig. 311. Section through Sporogonium of a moss plant.

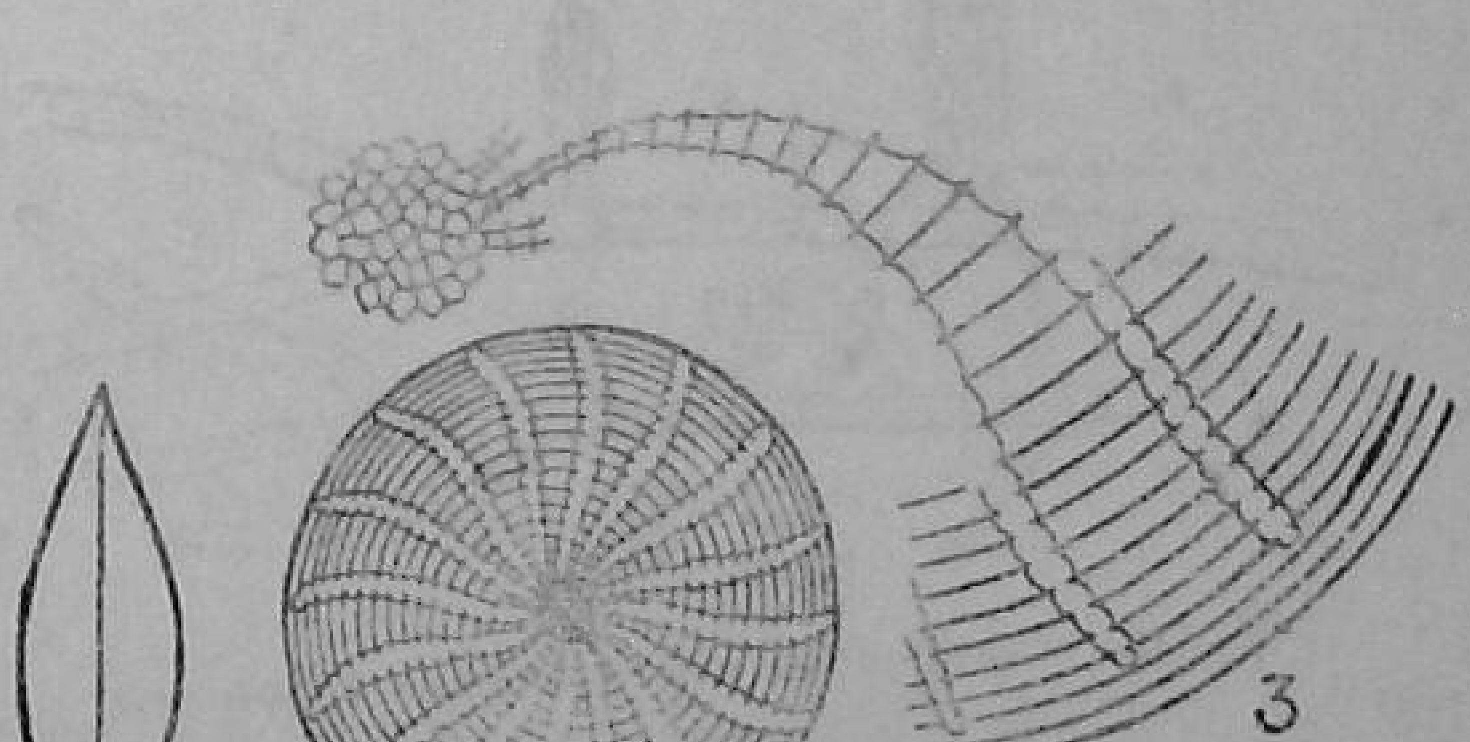

Fig. 312. *Funaria hygrometrica* 1. leaf; 2. peritome ; 3. a portion of the peristome showing one tooth.

The upper portion of the capsule is the part that contains the spores. In the centre of the capsule lies a core of sterile tissue constituting the **columella.** Surrounding this columella there is the **spore-sac,** and its inner wall consisting of a single layer of cells lies next to the columella, whilst its outer wall consisting of two or three layers of cells is separated from the cortex of the capsule by intercellular spaces. The layers of cells lying outside the air space which is traversed by strands of cells form the wall of the capsule. The cells in the wall of the capsule also contain chloroplasts. So the sporogonium is able to do photosynthetic work, and so it is semi-parasitic on the gametophyte. Within the spore-sac spores are formed and no elaters are developed. The peristome teeth being hygroscopic, spores can escape only during dry weather.

The spores germinate and give rise to green filamentous structures called **protonema.** (Fig. 313.) In some Mosses the protonema branches freely and forms green tangles persisting for long periods. The gametophyte arises as a lateral bud from protonemal threads. The formation of an extensively branched system of protonema is a special feature of Mosses. It is true that the spore of a Liverwort also puts forth a tube, but it is always short and further its free end very soon produces a mass of cells which develops into the Liverwort plant. (*See* Fig. 309 for Life cycle).

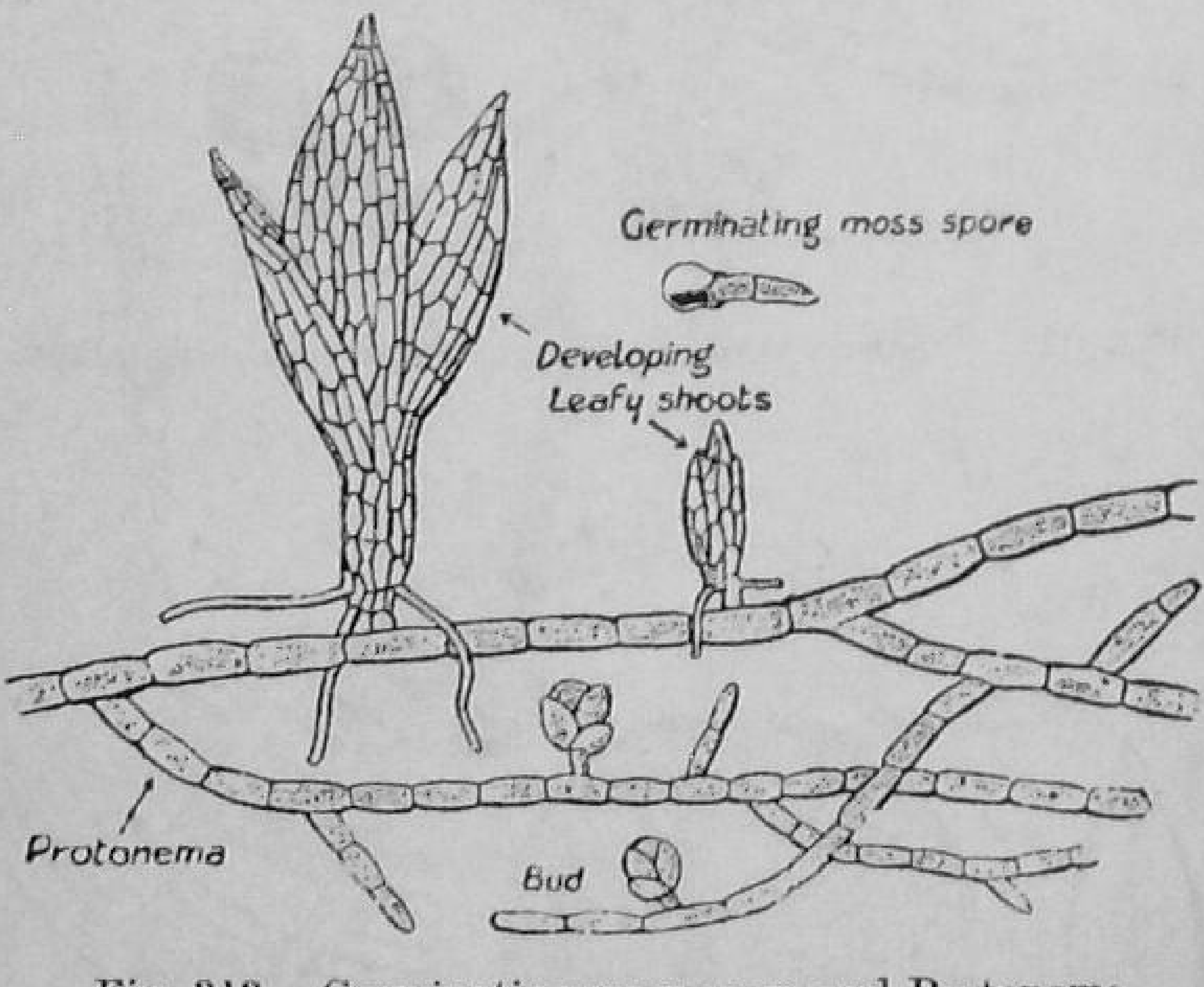

Fig. 313. Germinating moss spore and Protonema.

Besides the formation of spores, Mosses propagate themselves very freely by vegetative reproduction. This kind of propagation

seems to be more diversified and fruitful in Mosses than in any other portion of the vegetable kingdom. The cells of protonema are capable of each giving rise to a Moss-plant. Rhizoids produce very often protonema from which the normal plant arises, and sometimes rhizoids also give rise directly to the moss-plants. The gametophyte often forms gemmae and it is not unusual to have protonema developing from the leaves. Even parts of sporogonium are capable of producing protonema, which, in its turn, develops the plant. This great power of vegetative propagation is possessed even by *Funaria hygrometrica*. Rhizoid, stem, leaf and any part of the sporogonium can develop protonema. Gemmae do not seem to occur in this species. Now it must be obvious that the sporophyte generation is more highly developed in the *Musci* than in the *Hepaticae*. It is this sporophyte generation that becomes the most prominent generation in the groups higher than Bryophyta. The affinities of *Bryophyta* with other groups and the evolution of the sporophyte will be considered after dealing with the Pteridophyta.

CHAPTER XXXI

PTERIDOPHYTA OR THE VASCULAR CRYPTOGAMS

THE Vascular Cryptogams or the Pteridophyta consisting of Ferns, Water Ferns, Lycopodium and Selaginellas and Isoetales represent the most highly developed Cryptogams. They occupy a position intermediate between the Bryophyta and the Spermatophyta. Since this group forms antheridia and archegonia like the Bryophytes, both these groups are included under a special class termed **Archegoniatae.** Like the Bryophytes the Vascular

Fig. 314.—Tree Ferns.

Cryptogams also have in their life cycle two alternating generations. But the green leafy plant amongst Pteridophyta is the asexual generation or the sporophyte, whilst the conspicuous plant in Bryophyta is the sexual generation or the gametophyte. Further the sporophyte is a very large plant in proportion to the size of

the gametophyte in Vascular Cryptogams. Generally in this group the gametophyte is very small, inconspicuous and thalloid in form. Both the generations are capable of independent existence.

Fig. 315.—Tree Fern.

On account of the great diversity exhibited by plants of this group, we have to study as types certain species and we shall choose species of *Adiantum, Marsilia, Lycopodium and Selaginella.*

The common Maiden-hair-fern easily obtainable in gardens and conservatories is a typical example of Filices or true Ferns. We have a large number of species amongst true Ferns, and they are widely distributed. They generally flourish in shaded cool places, where water will become available in abundance at the time of fertilisation at least, since all ferns are absolutely dependent upon water for fertilisation. In habit and size these plants present a great diversity. We have Ferns not above an inch or

Fig. 316.—*Gleichenia linearis.*

two with a very delicate moss-like habit, such as some species of *Trichomanes.* Some species of *Lygodium* are creepers. There are some Ferns which monopolise large areas and become the dominant species. The Bracken-Fern, *Pteris aquilina*, is a most troublesome weed flourishing in the higher regions of Nilgiris and Pulney Hills. The Fern *Gleichenia linearis* (*G. dichotoma*) forms extensive thickets at the lower elevations in the Western Ghats of South India, in sheltered moist gulleys. (*See* Fig. 316). The greatest development is attained by Ferns in the tropics. All moist shady situations in the Hills abound in Ferns. On the hills of South India in such situations we also find Tree-Ferns growing luxuriantly, especially in sheltered situations and these belong to the genera *Alsophila* and *Cyathea.* (*See* Figs. 314 and 315).

Fig. 317.—*Adiantum capillus-veneris.* I. full plant; 2. the apical portion of the rhizome.

Type.—The Maiden-hair-fern, *Adiantum capillus-veneris*, consists of an underground stem or rhizome growing horizontally. Leaves arise from its upper part and adventitious roots from its lowerside. This Fern is a perennial plant. The rhizome is covered by thin scale-like structures called **ramenta.** Its elongation in the horizontal direction is chiefly due to the activity of its apical bud, which consists of the growing point and a rosette of young leaves all densely clothed with ramenta. Branching of the stem is neither frequent nor so profuse, as in the shoots of flowering plants. Occasionally the growing point becomes bifurcated and gives rise to two branches. Adventitious buds arise which develop into branches. Axillary buds so characteristic of flowering plants, are unknown amongst Ferns.

The most striking feature of this Fern is the production of much-divided leaves which, as in other Ferns, are always larger in proportion to the stem. When young, the leaf is circinnately folded and its growth is usually very slow, and the vigorous apical growth lasts for a long time. Ordinarily only one leaf develops and matures into an expanded frond in one season. The main petiole and its

branches are black and shining. The leaflets or pinnules are green, cuneiform with quite regular dichotomous venation.

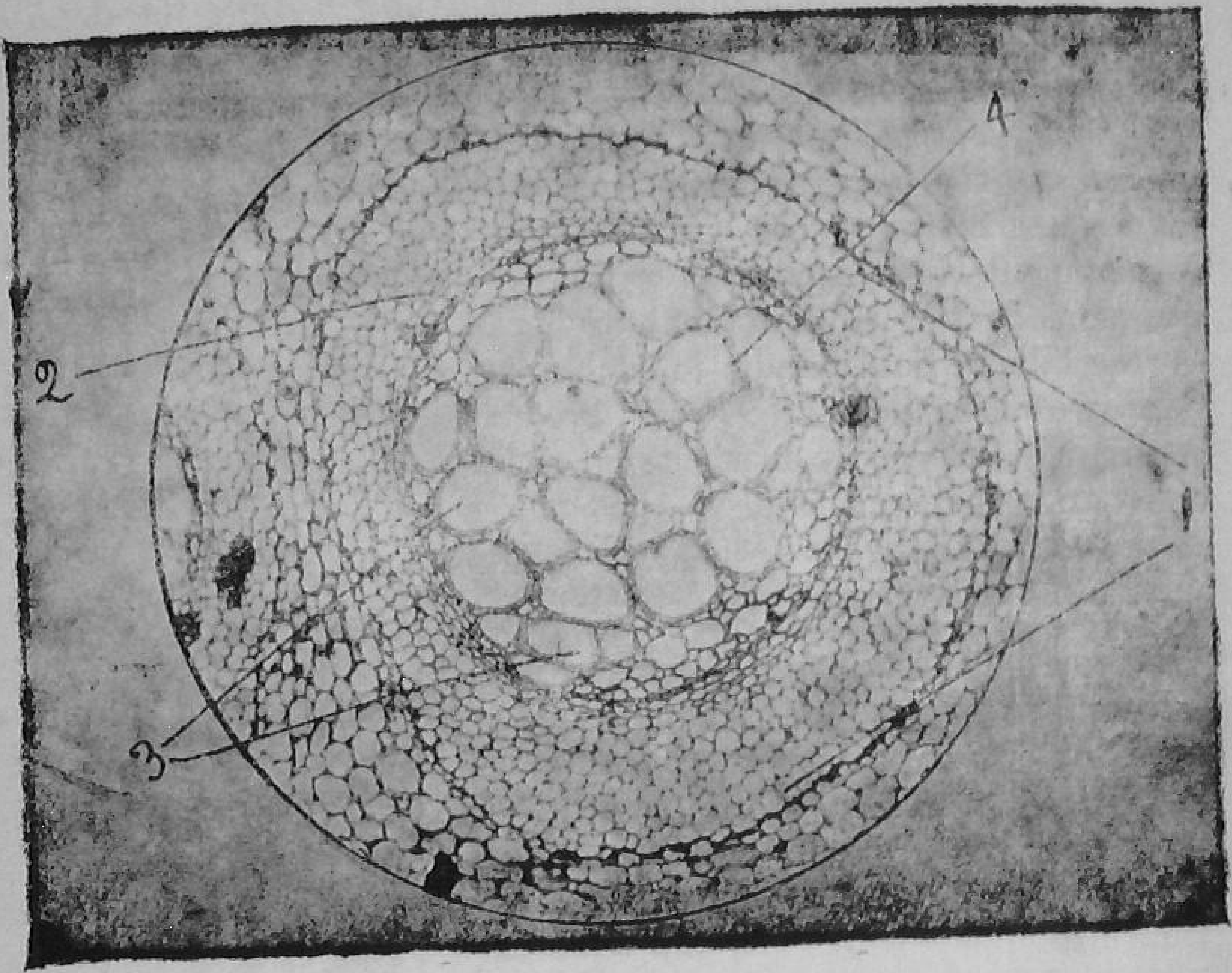

Fig. 318.—Transverse section of a vascular strand in the rhizome of a Fern. (Highly magnified), 1. vascular strand; 2. phloem; 3. xylem; 4. middle lamella.

The roots, though adventitious, resemble those of the seed-plants in every way.

In Ferns, the stem is essentially only the bearer of leaves and roots, and grows very slowly in length. It is woody and consists of tissues usually found in the stems of flowering-plants. In anatomical structure there is some resemblance between Ferns and flowering plants. The stem of *Adiantum* consists of a number of vascular strands embedded in the ground tissue which is parenchymatous. Very often strands of sclerenchyma also occur in the ground tissue, while hard stony or horny sheath frequently form the surface of stem and leaf-stalk.

In the transverse section of the stem of *Adiantum* we see a number of vascular strands disposed in the form of rings within a massive parenchymatous ground tissue. Each vascular strand consists of central core of xylem surrounded by the phloem. The

elements of xylem are mostly tracheids, the earlier ones **being spiral** and the later formed **scalariform.** The prominent **elements**

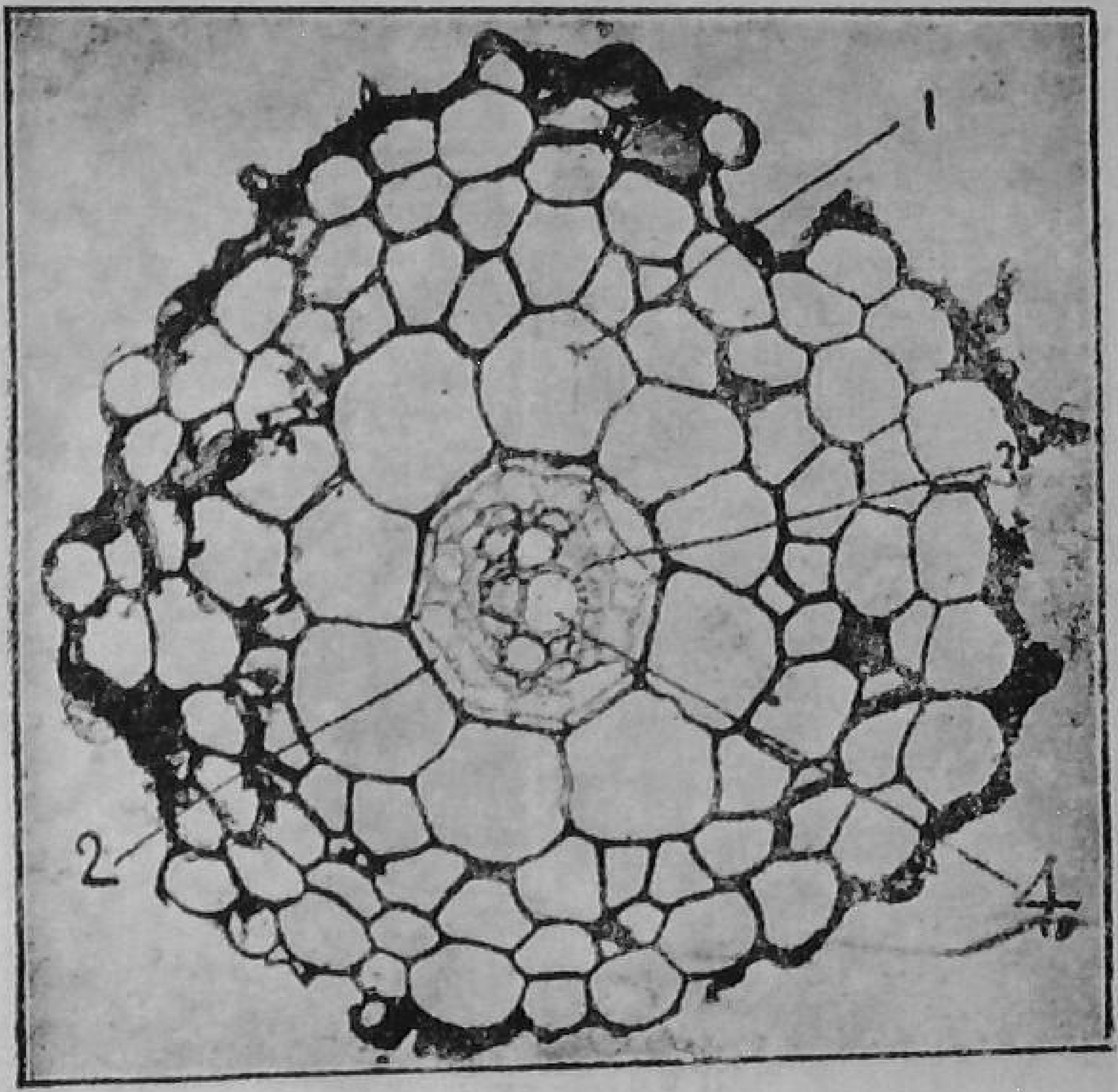

Fig. 319.—Transverse section of the root of *Adiantum* (Magnified) 1. Endodermis; 2. pericycle; 3. phloem; 4. xylem.

of phloem are large sieve-tubes, with the sieve plates disposed laterally. Companion cells are not present. No cambium is formed. Outside the phloem lie the pericyle and, outer to this, the endodermis surrounding the vascular bundle. This kind of structure is termed **polystelic** made up of a number of 'Steles.'

The growing point of the stem has in its apex a single large cell, tetrahedral in shape, instead of a group of cells.

The structure of the leaflets or pinnae resembles very much the structure of the leaves of flowering plants growing in shady situations. The epidermal cells of the fern leaf contain chloroplasts. The mesophyll cells of the pinnae constituting the chlorenchyma have air spaces amidst them, though the differentiation into palisade and spongy parenchyma is not very marked. The vascular strands traversing the leaflets are bicollateral in their structure. Stomata are numerous in the lower epidermis.

The structure of the root of *Adiantum* resembles very closely that of a diarch root of flowering plants. In this root there is a

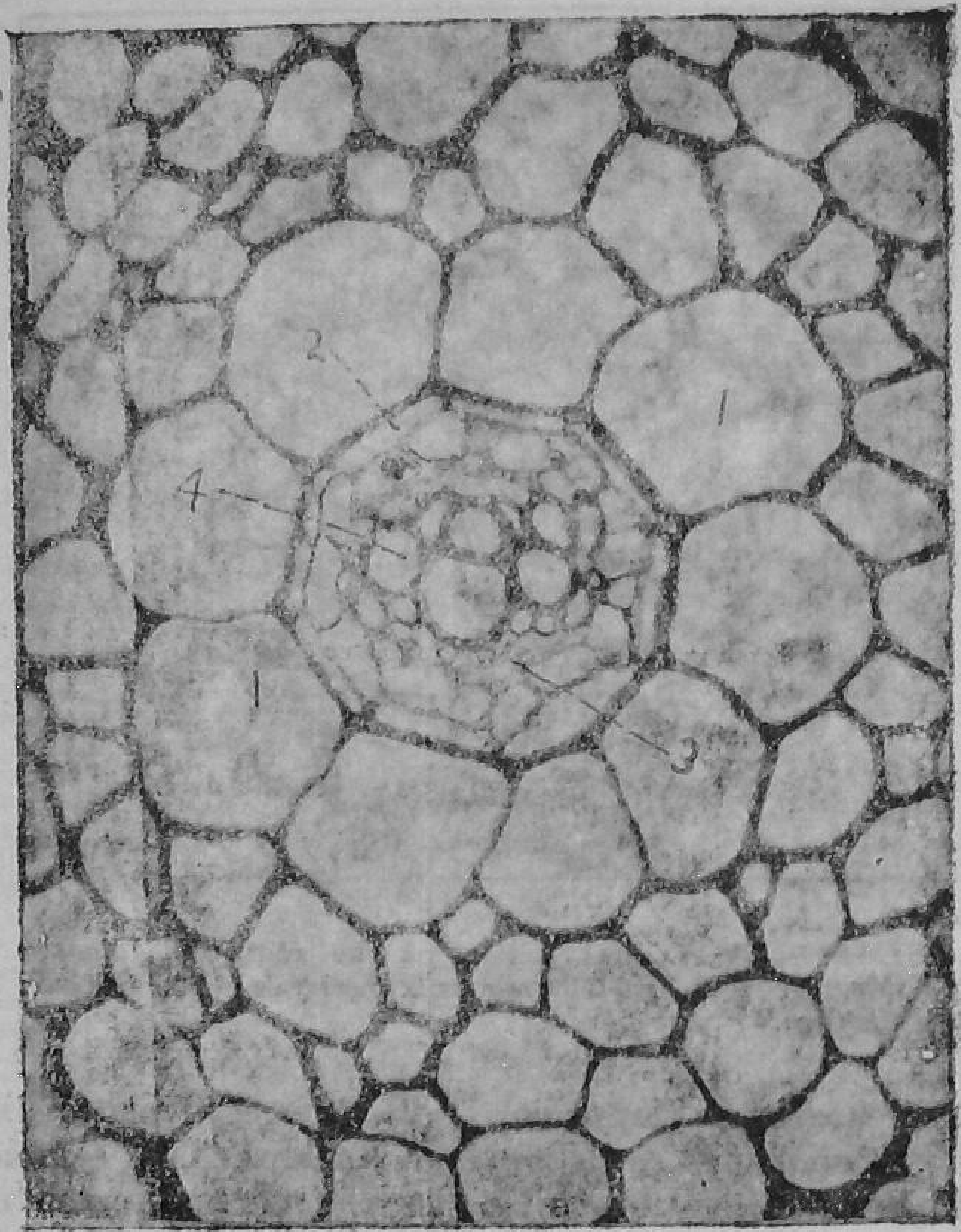

Fig. 320.—Transverse section of the root of *Adiantum* showing the stele 1. Endodermis ; 2. Pericycle ; 3. phloem ; 4. xylem, Highly magnified.

superficial piliferous layer, a broad cortex and a contracted stele. The stele is surrounded by an endodermis. The pericycle also exists. There are two protoxylem groups meeting in the centre and forming a plate with phloem on both the sides. The cortex consists of large parenchymatous cells.

Reproduction:—Asexual—The Fern plant being the sporophyte it must produce spores. The spores are formed within the spore-cases or **sporangia** as they are called, and on the lower surface of the leaflets sporangia are produced in large numbers. In *Adiantum* in

mature fronds, the edges of some of the pinnules are folded down. At first when the pinnae are young, these folds are not conspicuous, but become prominent later on as the pinnae get older. If these flaps are turned up, **brown** spots called **sori** become visible on the underside. Each sorus is a group of sporangia in different stage of development. The sori are connected with the ends of veins.

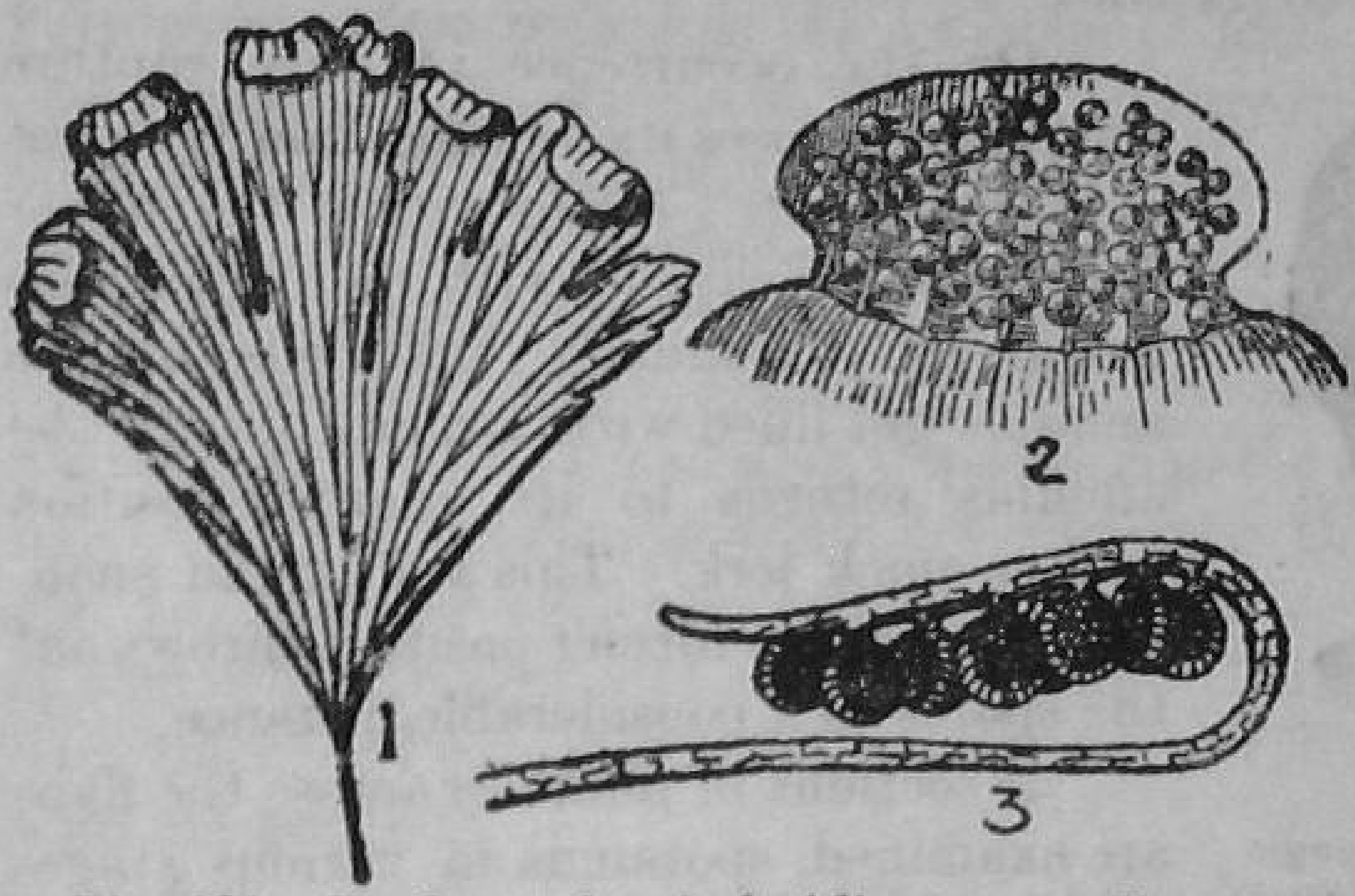

Fig. 321.—Leaflet and sori of *Adiantum capillus-veneris*. 1. a pinnule; 2. a flap turned up to show the sori; 3. section through the flap showing the sporangia.

A sporangium consists of a short stalk and a spore-sac or capsule containing spores or spore mother cells, according to the stage of development. The stalk is short and multicellular consisting of several rows of cells. The lateral wall of the somewhat lens-shaped capsule is composed of a single layer of flattened cells, all thin-walled, while a ring of thick-walled cells called **annulus** runs up from the top of the stalk on one side, over the top of the capsule to about the middle of the other side. In each of the cells of the annulus the inner and the radial walls are thickened, whilst the outer and the side walls remain thin. Between the end of the annulus and the top of the stalk, a number of thin-walled cells are found. This part is called the **Stomium**, and this being the weakest point dehiscence occurs here.

The sporangia, when ripe, contain spores inside and dehiscence is caused by the movement of annulus brought about by its rupture at the stomium. So long as the sporangium is young, all its cells contain water, and hence all of them will be turgid. But with the ripening of the sporangium there will be a gradual diminution of water and this must necessarily affect the annulus. In consequence of the escape of water, the thin walls of the cell forming the annulus begin to shrink, and at the same time the thickened radial wall will tend to come close together. As the loss of water affects all the cells of the annulus, it tends to shrink as a whole and this must necessarily cause the rupture of

the sporangium at the stomium. As the lateral portions of the capsule consist of thin-walled cells, the splitting will extend from the weakest point to its sides.

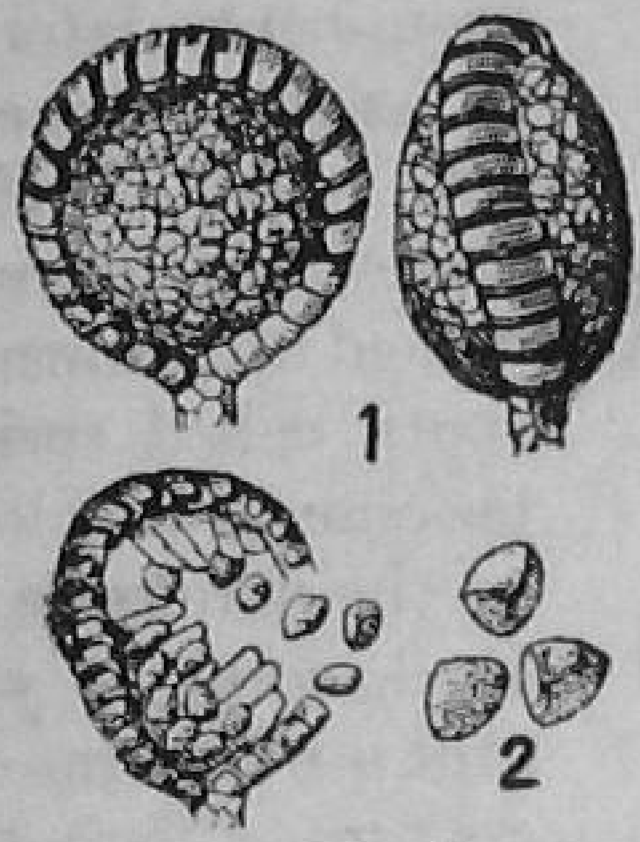

Fig. 322.—Sporangia and spores of *Adiantum capillus-veneris*. 1. sporangia; 2. spores, Highly magnified.

On the occurrence of this rupture the annulus loses its tension and becomes almost straight. Along with it the upper portion of the capsule with spores will also be carried. Gradually the cells of the annulus get filled with air, and finally the annulus returns to its original position with a quick jerk. This very rapid snapping back to its former position throws out the spores to a considerable distance.

If sections of pinnules across the flaps are examined, sporangia in various stages of development may be seen, and they would be found connected with the prolongations of the veins. A sporangium is formed from a single superficial cell of the pinna by successive segmentations. By repeated divisions the stalk and the capsule are formed. The capsule consists of a wall enclosing sporogenous tissue, and immediately outside this sporogenous tissue may be seen in the early stages one or two layers of flat cells lying next to the wall of the capsule. The inner layer of cells found lying close to the sporogenous tissue forms the **tapetum.** The cells of the sporogenous tissue develop into spore-mother-cells. The tapetal cells get disorganised and serve as nutritive cells for the spore-mother-cells. Gradually the nutritive cells are absorbed, and the spore-sac will ultimately consist of the wall of the capsule and the spore-mother-cells within. Each spore-mother-cell divides into four spores. During the cell-division leading to the formation of spores, the first division of the nuclei is a reduction division. The development of spore-mother-cells into spores by reduction division is exactly similar to the formation of pollen-grains in the pollen sacs of anthers.

The leaves of *Adiantum* bearing the sporangia are exactly like foliage leaves. The former are often called **sporophylls** and in some Vascular Cryptogams, the two kinds of leaves, namely sporophylls and vegetative leaves, are very well differentiated.

2. **Sexual.**—The spores of this Fern are very small and light. A spore is really a single cell covered by two distinct membranes, namely, an **endospore** or an internal layer of cellulose and an **exospore** or a cutinised external layer. The spores are produced in

enormous numbers and they are all of only one kind. Hence this Fern plant is **homosporous.** As a matter of fact, all true Ferns are homosporous. The spores of Ferns being very small and light they float in the atmosphere like dust. When spores are sown on moist earth, or on brick, or pieces of tile standing in water, and kept in moist air they germinate and form small green, thin bodies called **prothalli.** A prothallus when fully formed is somewhat heart-shaped with a broad deep depression in the front. It becomes fixed to the soil or substratum by numerous rhizoids. As a rule the prothallus is only one cell thick, except in the middle which is somewhat thicker and consists of more than one layer of cells. This thickened part is called the cushion. All the cells are provided with chloroplasts.

The prothallus is able to lead an independent existence although it is small and never grows larger than half an inch. It forms the **sexual generation** or **the gametophyte.** For its development and for the fulfilment of its part in the life cycle of the Fern, a moist habitat is a necessity. The sexual organs, **antheridia** and **archegonia** are developed on the **lower surface of the prothallus.**

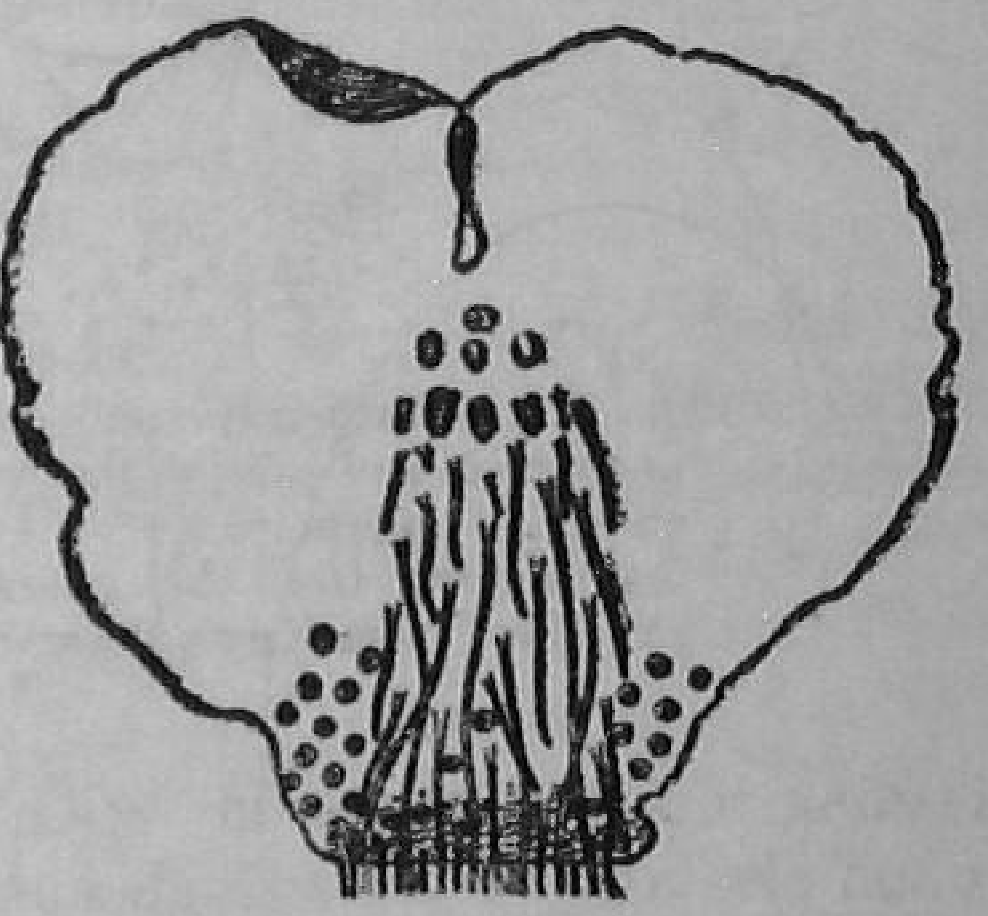

Fig. 323.—Prothallus of a Fern..

The **antheridia** are usually found towards the base of the prothallus amidst the rhizoids. They are small outgrowths consisting of a mass of cells enclosed by a wall of one layer of dome-shaped cells. The central mass of cells develops into spermatozoid mother-cells. When the antheridium is mature its wall bursts at the top setting free the sperms. For the proper development and rupture of the antheridia, external water is necessary. The escape of the spermatozoids from them is possible only when water is available. The spermatozoids have many cilia and they can move about only in water. The antheridium is formed from a single superficial cell.

The archegonia are found somewhat close to the depression in front of the prothallus, and a little to the front of the antheridia. Each archegonium consists of a short neck bent over and away from the growing point and a flask-shaped portion or venter

immersed in the body of the prothallus. It is the neck alone that protrudes beyond the surface of the thallus. The neck has a canal

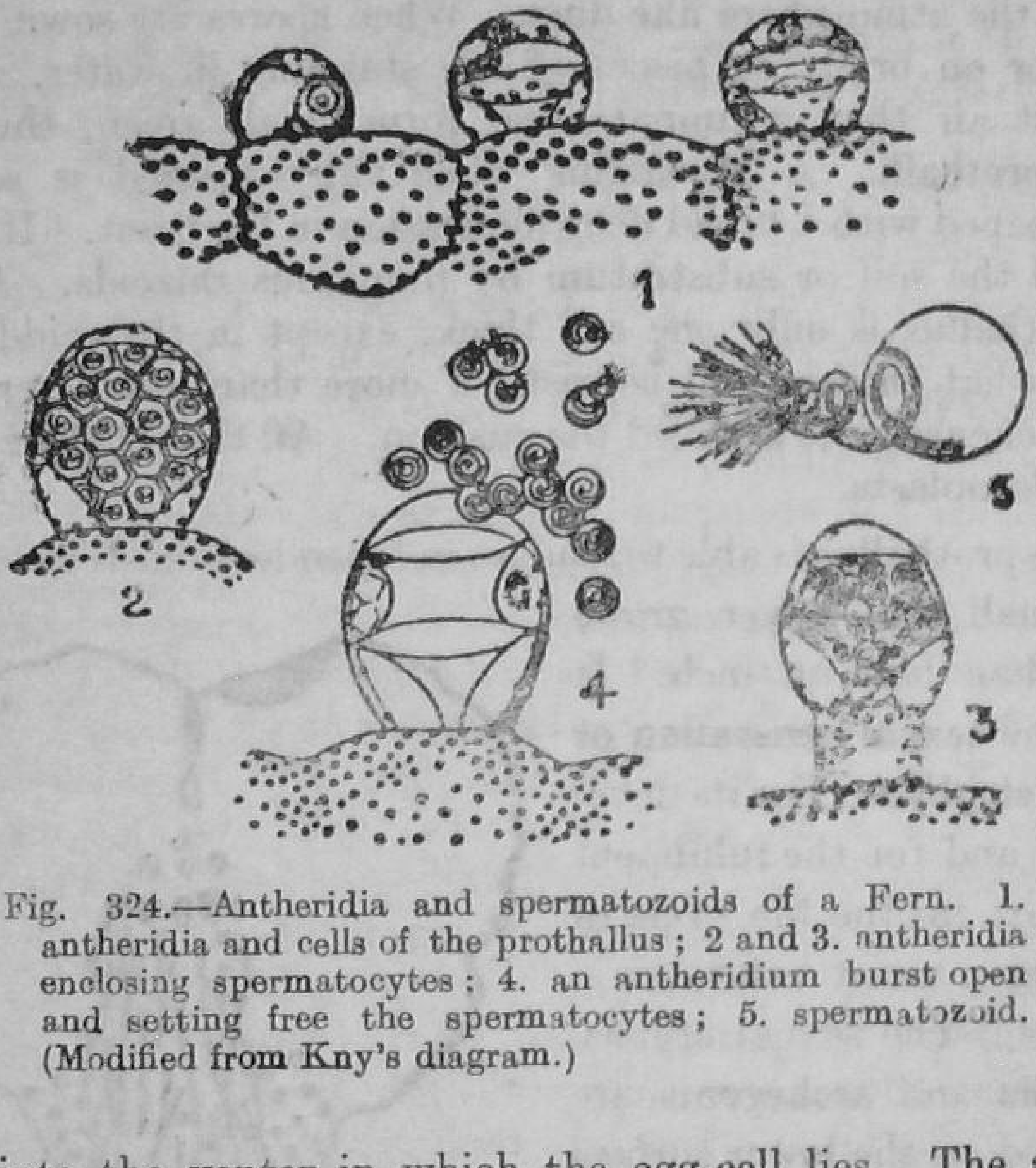

Fig. 324.—Antheridia and spermatozoids of a Fern. 1. antheridia and cells of the prothallus ; 2 and 3. antheridia enclosing spermatocytes ; 4. an antheridium burst open and setting free the spermatocytes ; 5. spermatozoid. (Modified from Kny's diagram.)

leading into the venter in which the egg-cell lies. The archegonium also arises from a single superficial cell of the thallus. Like the antheridia, archegonia also need external water for their opening at the free end of their necks to allow the spermatozoids to enter.

The spermatozoids are attracted to the mouth of the archegonia by the malic acid in the mucilaginous substance present in the neck-canal. They are caught in the viscid substance lying at the broad mouth of the neck of the archegonium. Working its way through the neck-canal, the spermatozoid reaches the **oosphere** or **egg-cell** and fuses with it. The single cell resulting from the fusion of the egg-cell and the sperm-cell (oospore) begins to divide repeatedly and finally develops into the ordinary Fern plant.

Embryo.—The zygote or the oospore divides into eight cells and the upper four by further division give rise to the axis and the leaves, and from the four lower cells the foot and the root develop. In the embryo illustrated here the leaf, the foot, the future axis, and the root are clearly seen. (*See* Fig. 325.)

In *Adiantum* and all true Ferns the sporangia consist of **a wall of only one layer of cells with transverse or longitudinal dehiscence.**

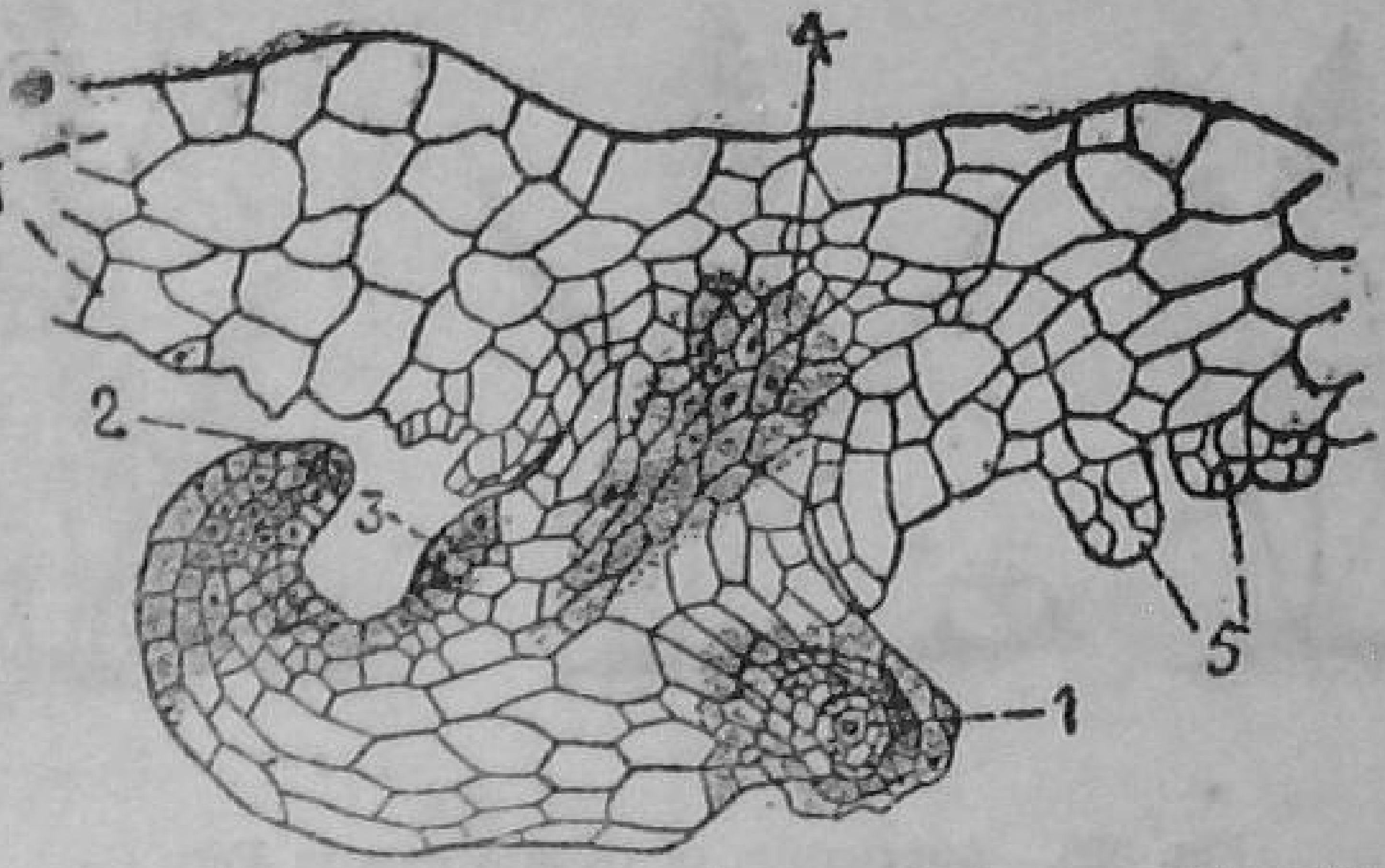

Fig. 325.—Section of a young sporophyte growing out from the prothallus of a Fern, highly magnified. root-apex ; 2. leaf-tip ; 3. growing point of the stem ; 1, 4, foot ; 5. archegonia ; 6. body of the prothallus.

Classification :—A distinct annulus is present, though its position in the sporangium may vary. These Ferns which embrace the largest number of species are included under the class **Leptosporangiate** Ferns. There are some Ferns, such as *Marattia, Angiopteris, Ophioglossum* and *Botrychium* in which the sporangia have walls formed of a number of layers of cells. There is no annulus, and the sporangia dehisce by longitudinal slits. The sporangia are developed on the lower surface of the leaves in the first two genera, whilst in the third and the fourth, they are borne by the leaves as special segments quite distinct from the green flat leaf segments. In *Ophioglossum* the sporangia are borne by a simple cylindrical spike, but in *Botrychium* the part bearing the sporangia is a pinnately branched spike. (*See* Fig. 328). These constitute the class of **Eusporangiate** Ferns.

Alternation of Generations.—The life history of the Fern plant is most interesting. It has two distinct phases in its life-cycle, namely, the prothallus or the **gametophyte** and the Fern plant or the **sporophyte.** These two generations regularly alternate and, as already stated, the alternation of generations is a typical feature of the Ferns. Compared with the Bryophytes, the sporophytes of ferns are very much advanced, and they lead an independent existence and are not dependent on the gametophyte. The adaptation, already foreshadowed in Bryophyta to a life on land,

is perfected in Ferns in their sporophytes. The sterile tissue has increased to enable the plants to adjust itself to its surroundings

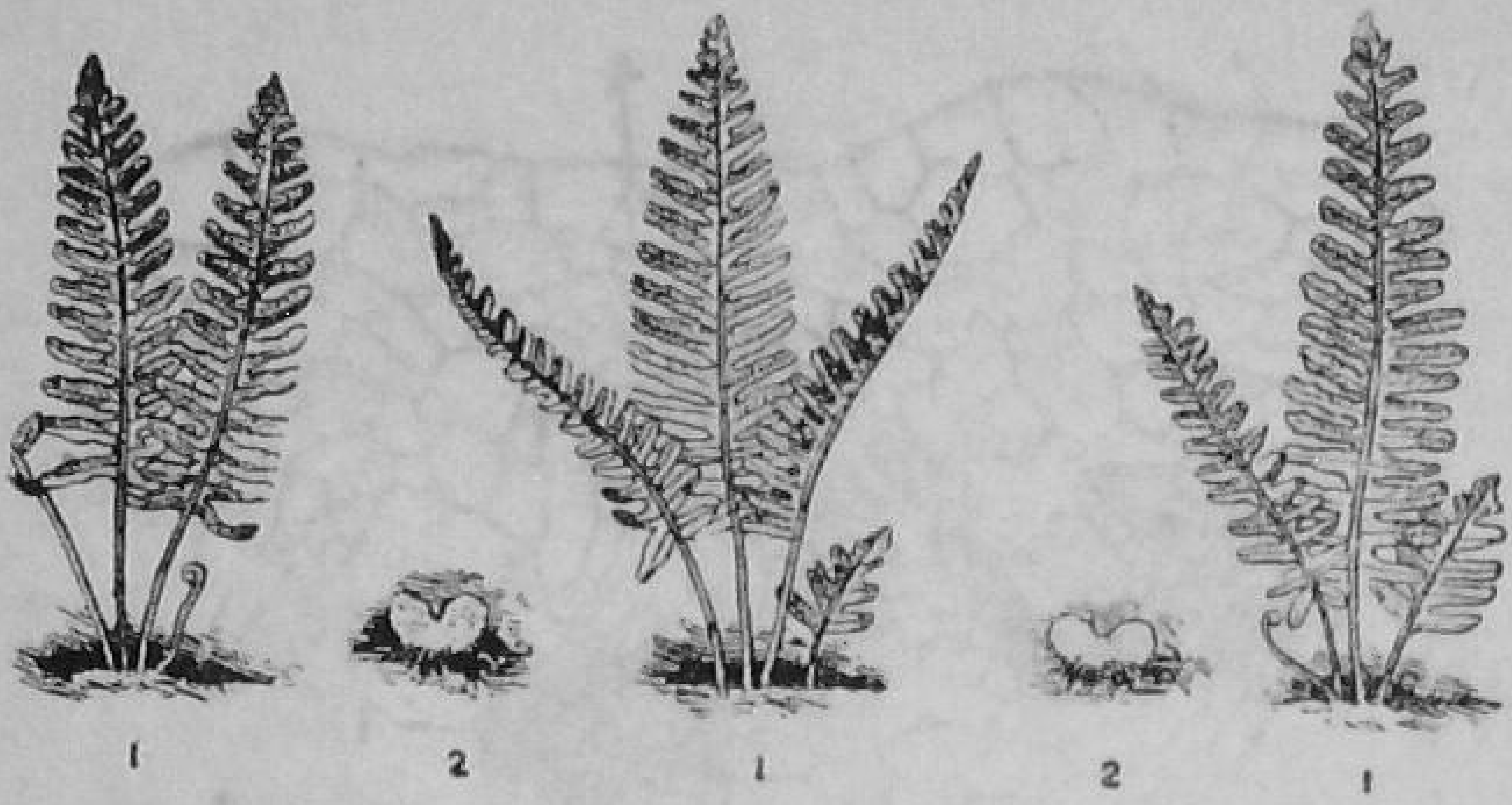

Fig. 326.—Alternation of Generations in Fern

much better, and the sporogenous tissue is external. On account of this arrangement the plant is able to produce enormous amount of spores and compete successfully in the struggle for existence.

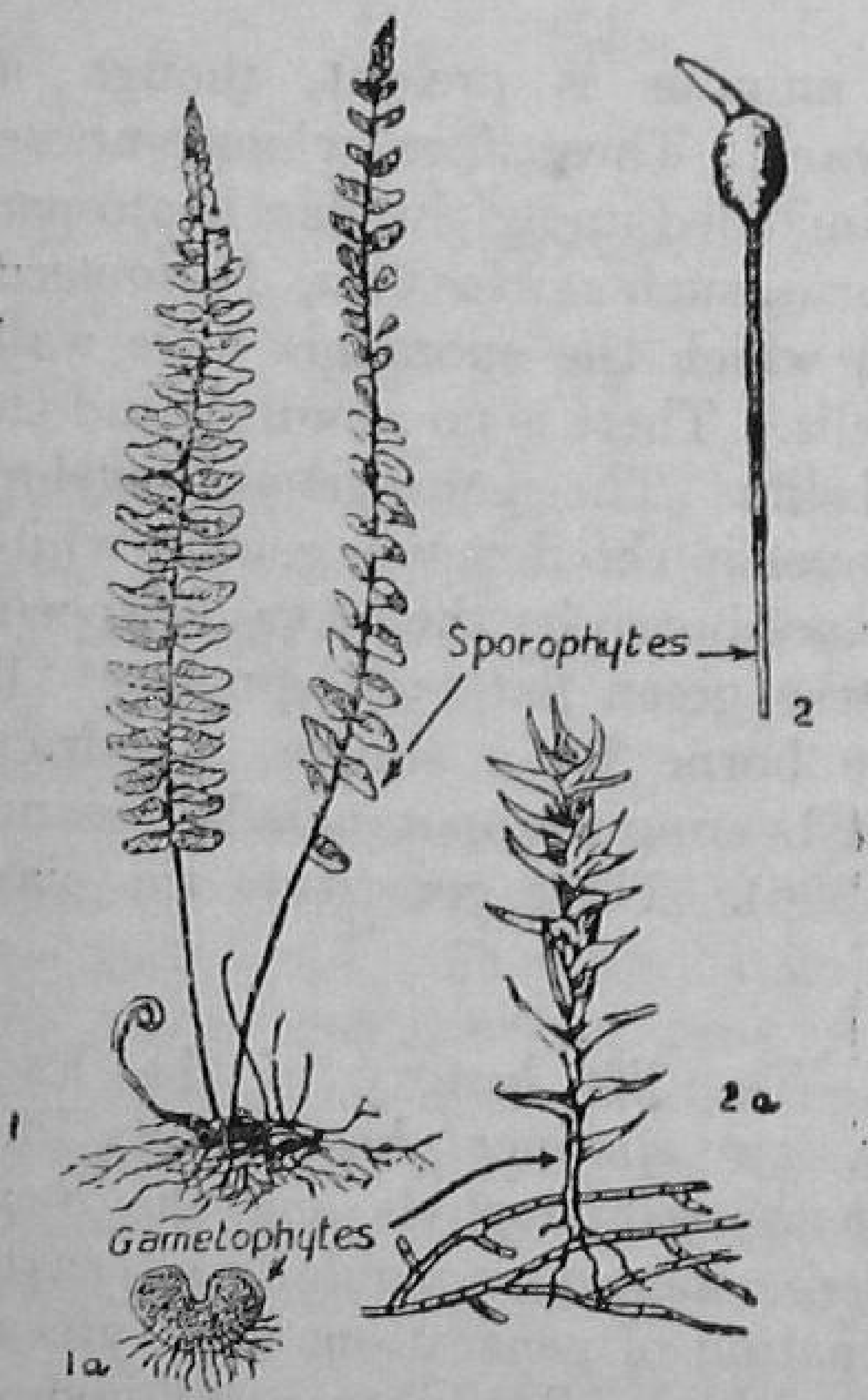

Fig. 327.—Moss and Fern compared

Fig. 328.—*Botrychium*. An Eusporangiate Fern. Note the branched segment bearing sporangia.

The gametophyte, on the other hand, is small and inconspicuous and retains a thalloid structure throughout its life, although

in Bryophytes this is the generation that is better developed and conspicuous. It is adapted for life in moist situations only and the object of its existence, namely, fertilisation is possible only in the presence of water. The gametophyte is the haploid generation as reduction division occurs during the formation of spores, and the sporophyte is the diploid generation since the nuclei get a double set of chromosomes as the result of fusion of the sexual cells. The zygote and the spore form the beginnings of the sporophyte and the gametophyte respectively.

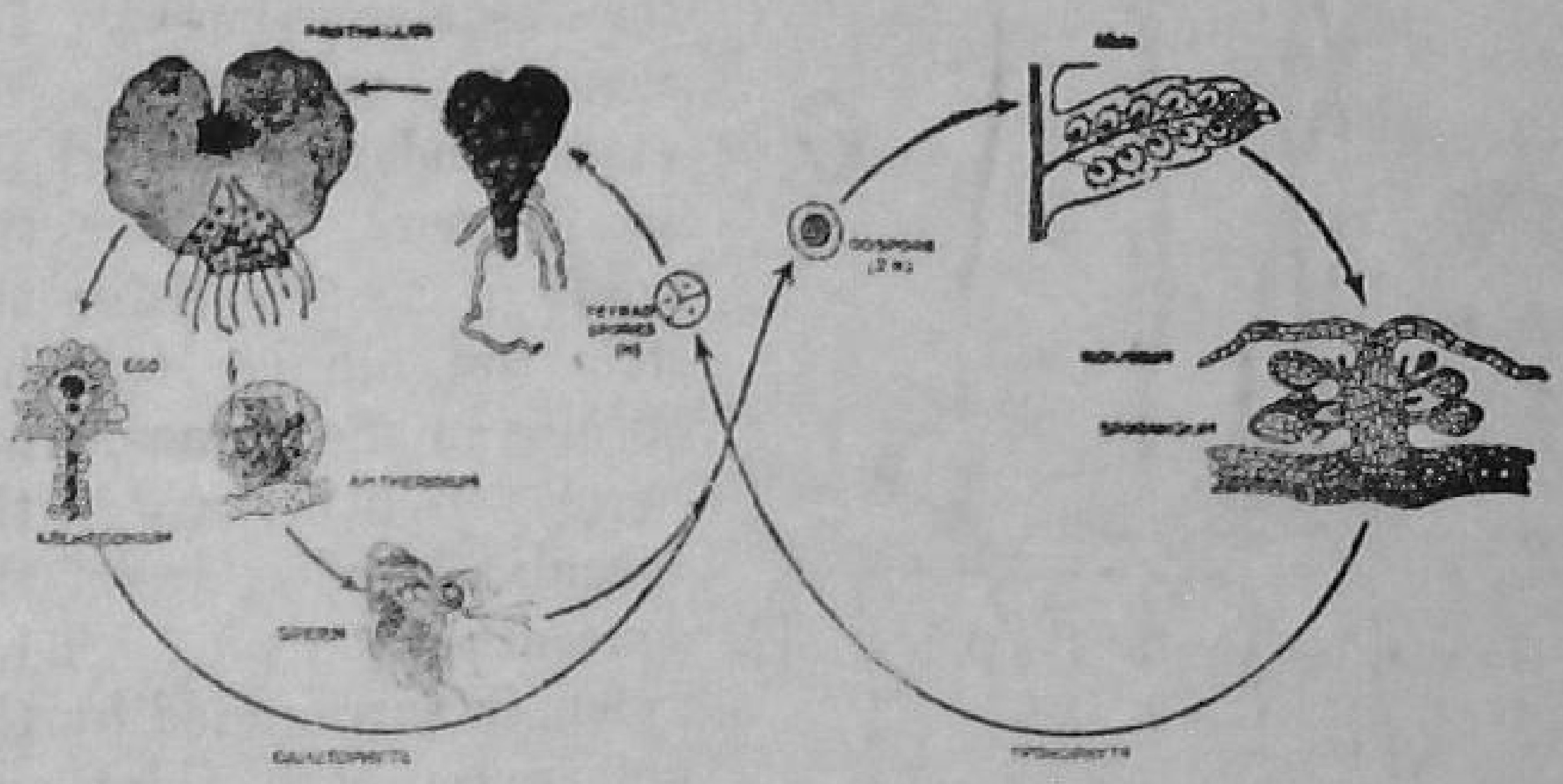

Fig. 329.—Fern-Life cycle

MARSILIA OR WATER-FERN

The marsh-weed *Marsilia minuta* is a Fern though it does not appear to be so at first sight. The plant is easily recognised by its creeping stem and long-stalked leaves with four spreading cuneate leaflets. The weed is the sporophyte adapted for living either as a marsh-plant or an aquatic plant.

The creeping stem is slender and cylindrical and branches freely as in *Adiantum*, the leaves arise from the dorsal side, and the ventral side gives off adventitious roots. A transverse section of the stem shows a compact central stele, surrounded by a fairly large cortex. Being aquatic in habit, numerous air cavities occur in the peripheral portion of the cortex. These cavities are separated from one another by radial trabeculæ. In young stems diaphragms stretched across the air spaces are also seen. Externally there are two layers of cells overlying the air cavities. The inner portion of the cortex is compact and consists of several layers of cells. In this inner portion of the cortex two or three layers of cells lying close to the air cavities become thickened as the stem gets older. The vascular bundles form a

cylinder in the centre of the stele and the hollow centre of this cylinder is filled with parenchymatous cells. There are two distinct layers of endodermis, one forming the external boundary of the stele and the other surrounding the central core of the fundamental tissue lying within the vascular cylinder. The elements composing the xylem and phloem and the arrangement of these two kinds of tissues within the stele are similar to what obtains in the homosporous Ferns. In other words, the vascular bundles are of the concentric type. The xylem is surrounded by the phloem on both sides and such a bundle is described as **amphiphloic siphonostele.**

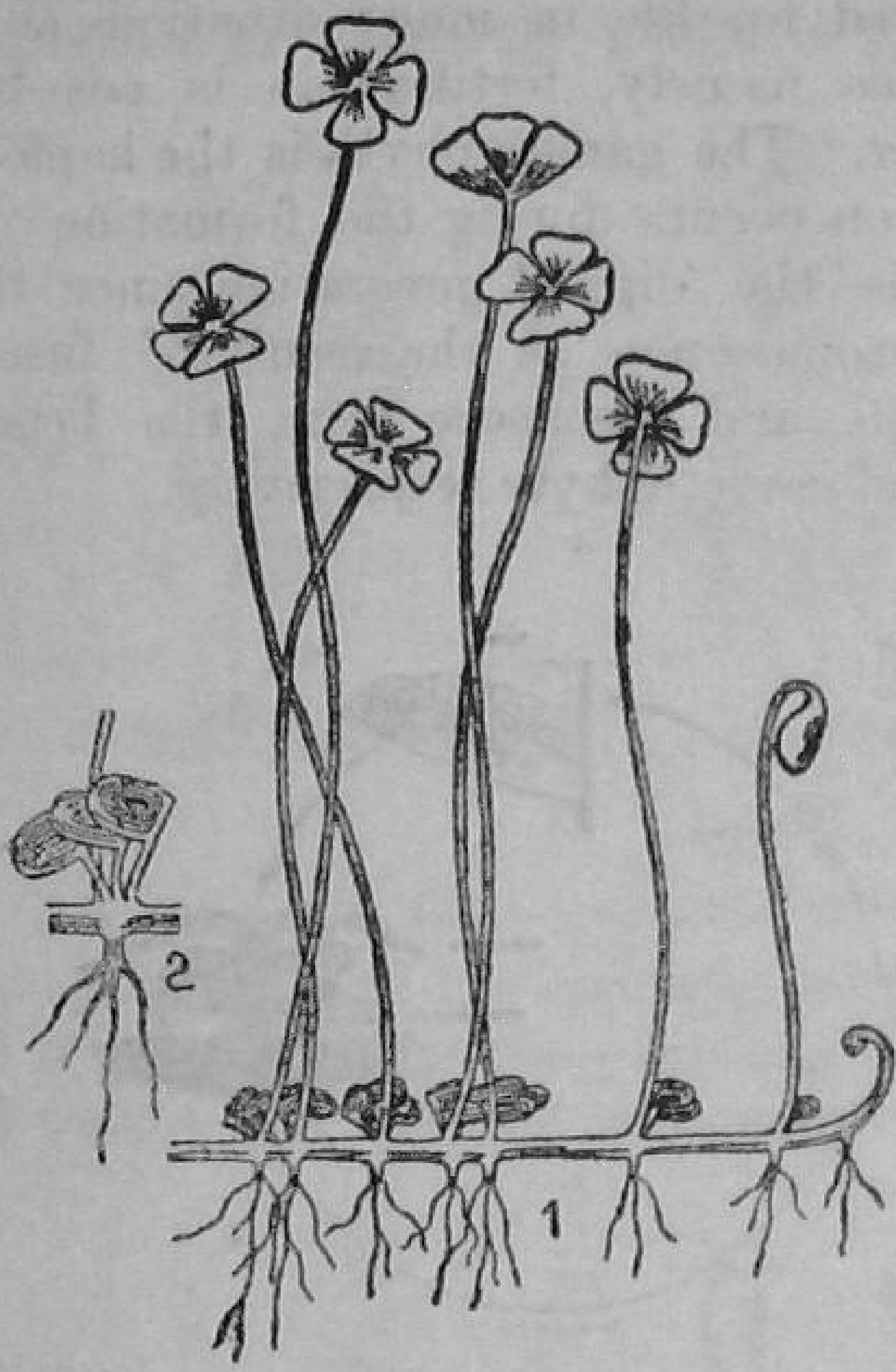

Fig. 330.—*Marsilia minuta*, L. 1. Full plant; 2. sporocarps.

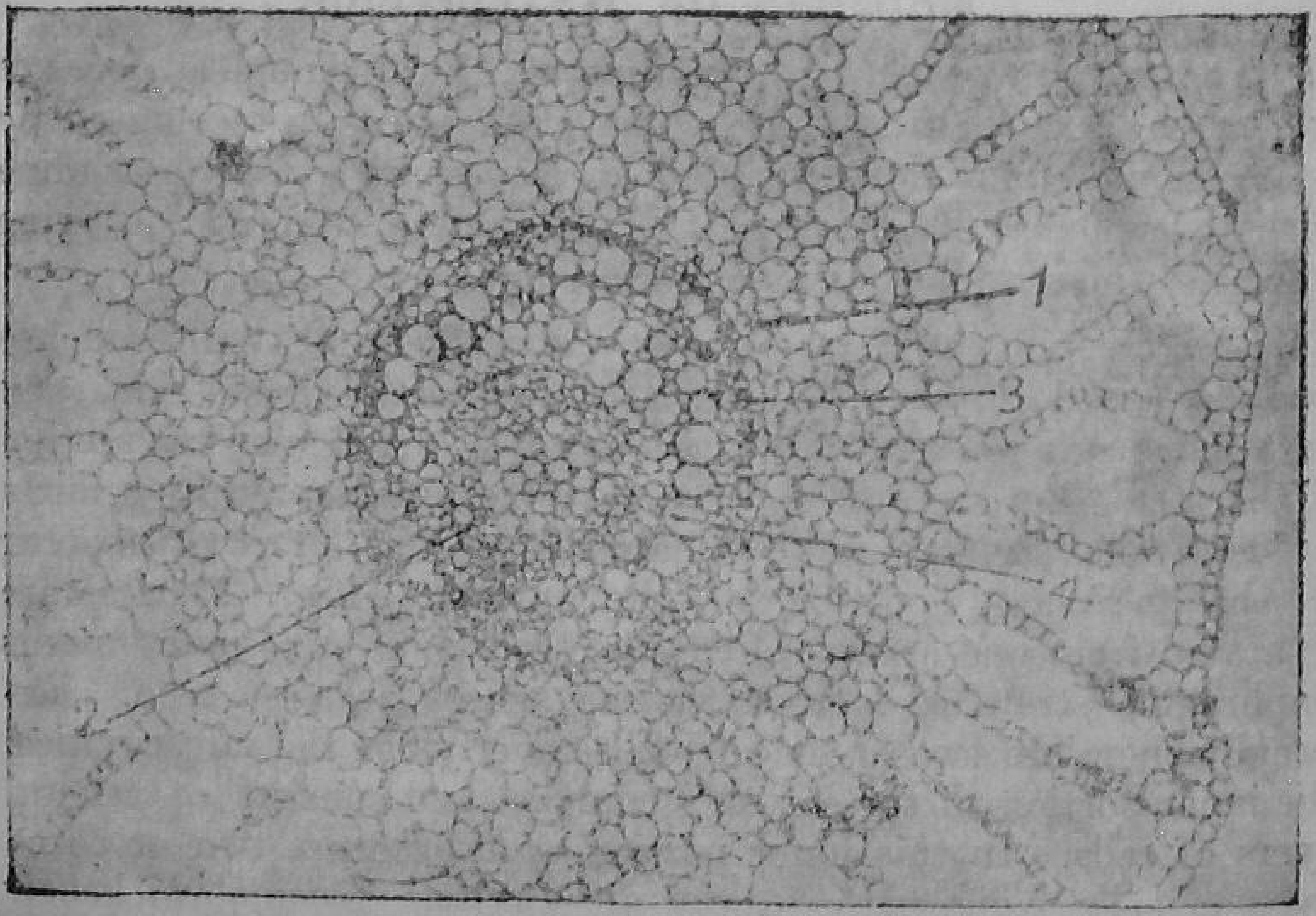

Fig. 331.—Transverse section of the stem of *Marsilia coromandelica* as seen under low power. 1. outer endodermis; 2. inner endodermis 3. phloem; 4. xylem.

Leaves are circinately folded when young as in other Ferns. The leaf has a long petiole bearing two pairs of lobed leaflets

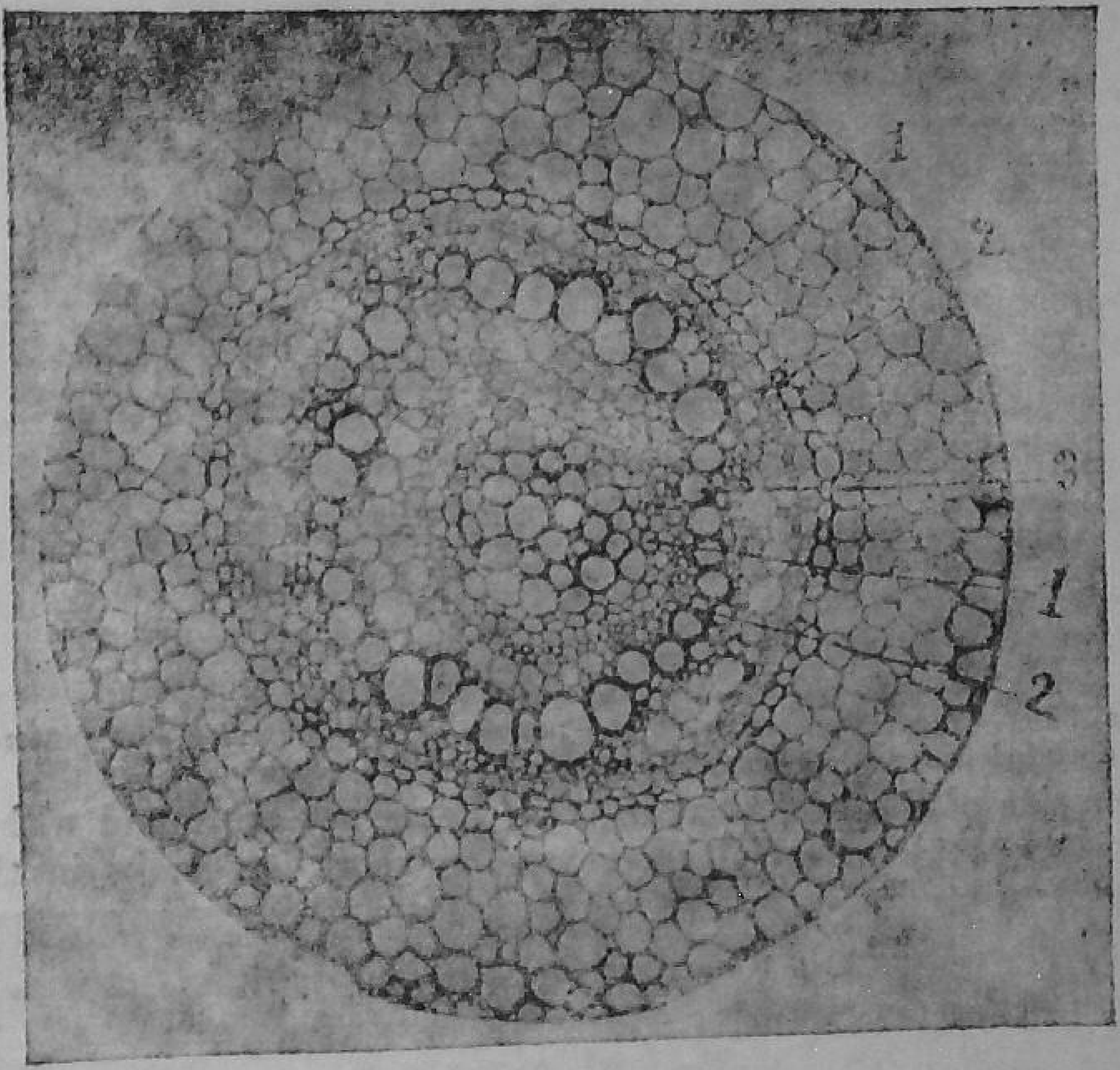

Fig. 332.—Transverse section of the stem of *Marsilia coromandelica* showing the stele as seen under high power. 1. endodermis; 2. phloem; 3. xylem.

cuneate in shape. The margins of the leaflets are irregularly toothed. Of the four leaflets two are inserted a bit higher than the opposite pair. The venation of the leaflets is of the forked or dichotomous type.

The structure of the petiole is more or less similar to that of the stem. The cortex possesses air-spaces like the stem, but there is only one endodermis. The vascular bundle is smaller and the xylem is surrounded by the phloem.

Heterospory.—This plant produces spore of two kinds, namely, small spores called **microspores** and very large spores termed the **megaspores.** Both kinds of spores are formed within separate sporangia, the miscrospores in **microsporangia** and megaspores in **megasporangia,** and these two kinds of sporangia are collected together in **sori.** Each sorus consists of a few megasporangia and a number of microsporangia. The sori do not appear on the

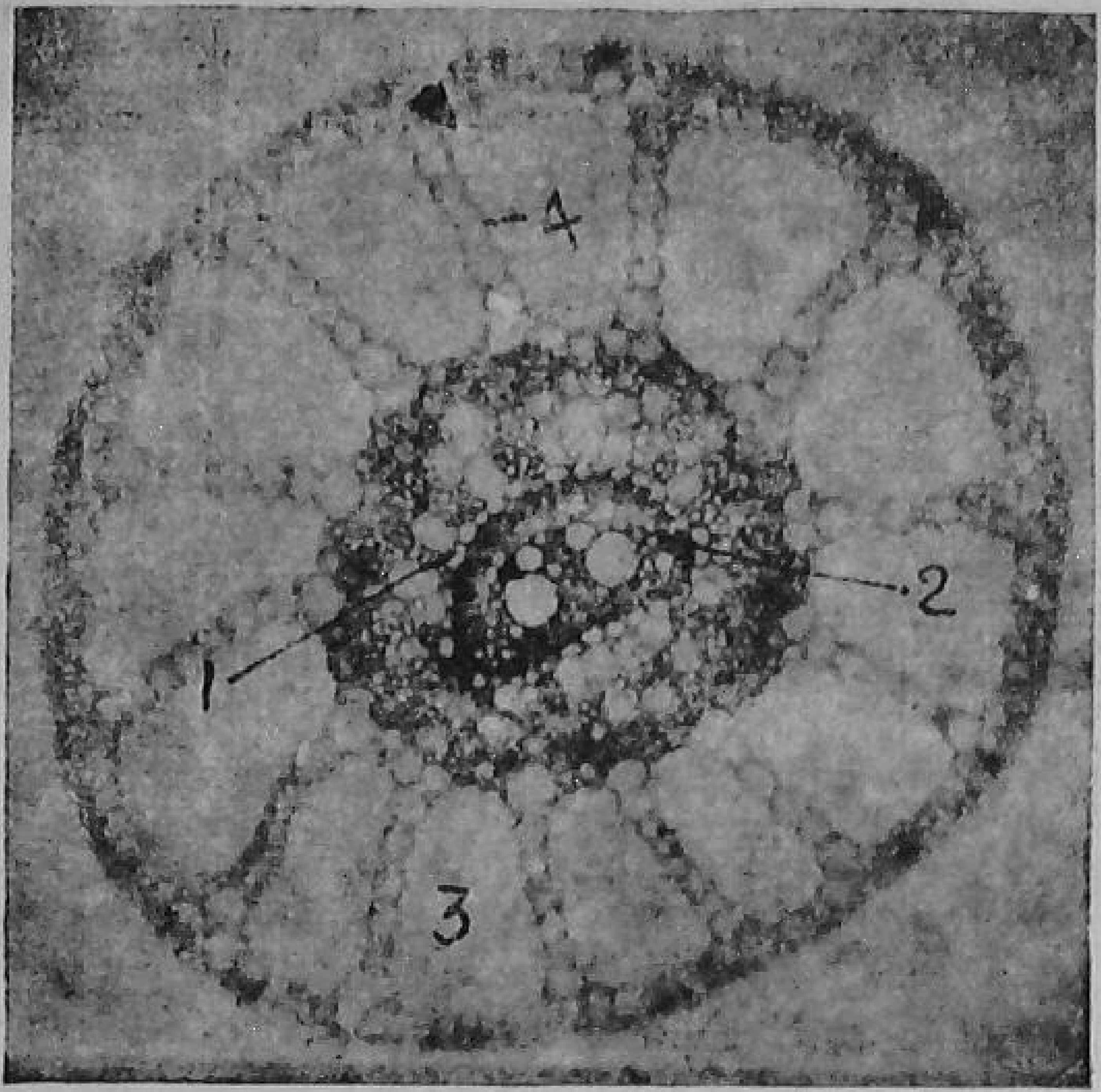

Fig 333.—Transverse section of the petiole of *Marsilia*under low power. 1. endodermis; 2. xylem; 3. aircavity; 4· trabeculae.

wer side of the leaflets as in other Ferns but are found within ·ecial receptacles called **sporocarps** on short leaf-stalks in the

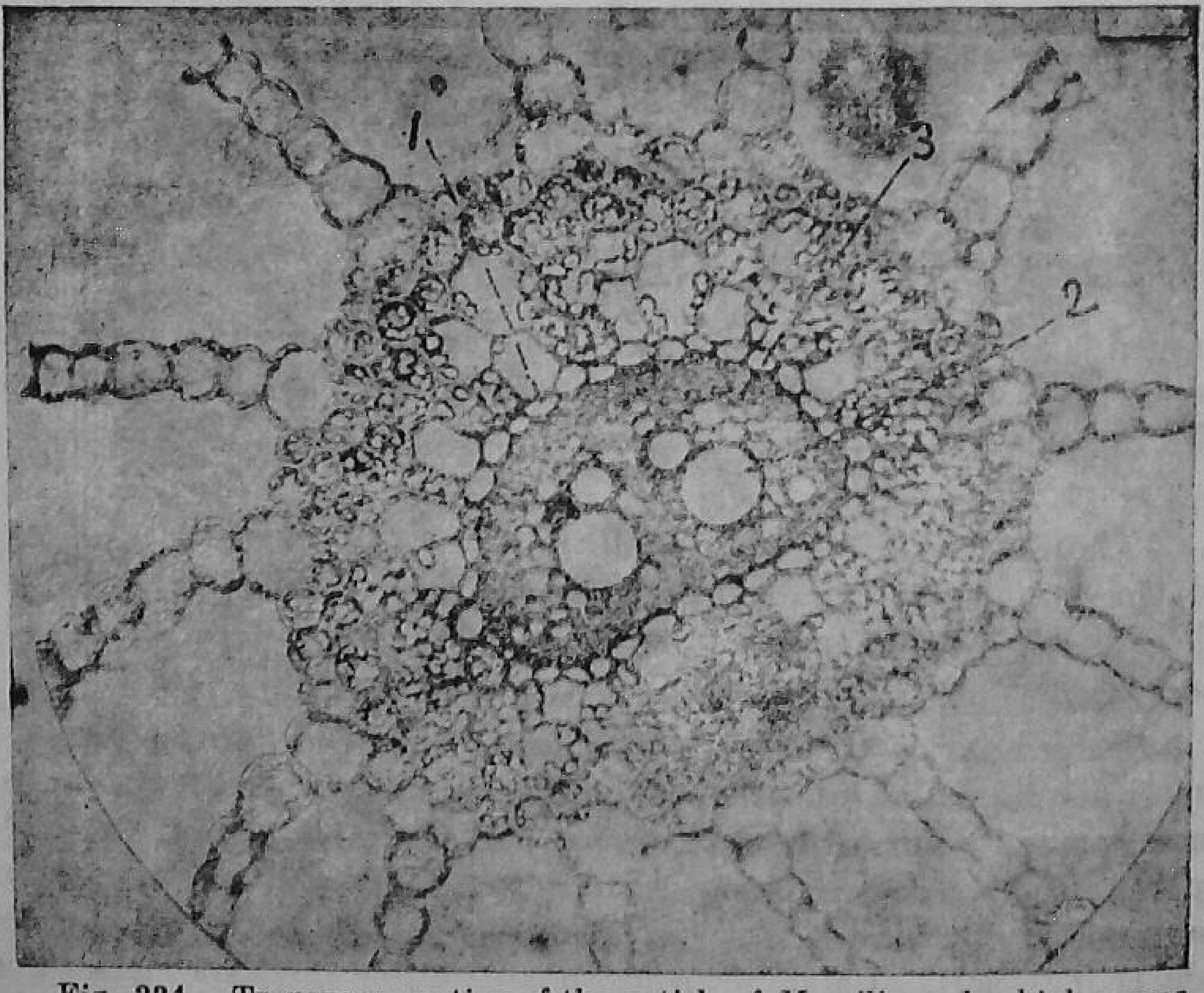

Fig. 334.—Transverse section of the peticle of *Marsilia* under high power 1. endodermis; 2. xylem; 3. phloem.

place of leaflets. The sporocarp is a bean-shaped body with a very hard rind, within which the sori are disposed in two rows on its sides. All the sori are attached to a mucilaginous ring running round the sporocarp. When a sporocarp is placed in water after scraping the hard shell in one or two places, it splits and from within the ring which now becomes swollen, comes out bearing on it a large number of sori.

The sporocarps are hardy bodies retaining their vitality for a very long time. The hard shell is impervious to water and forms an efficient protective covering for the sporangia. Sporocarps taken from herbarium sheets collected half a century ago and those preserved in 90 per cent. spirit resume their activity as soon as they are placed in water.

Sexual Reproduction.—As a consequence of *heterospory* the development of the gametophyte is also affected. Since there are two kinds of spores, two distinct gametophytes are formed, and they are very much reduced and do not emerge from the spores. The microspore germinates and a number of spermatozoids come out of it as the result of germination. The male gametophyte consists of a single cell and a single antheridium, formed inside the microspore. The spermatozoid is a coiled body with a large number of cilia attached to the lower coils. The megaspore germinates and forms a small female gametophyte with a single archegonium. As the megaspore possesses an external layer which becomes mucilaginous when placed in water, on germination a thick mucilaginous layer is formed and at the top of the spore a deep depression is formed, and it is

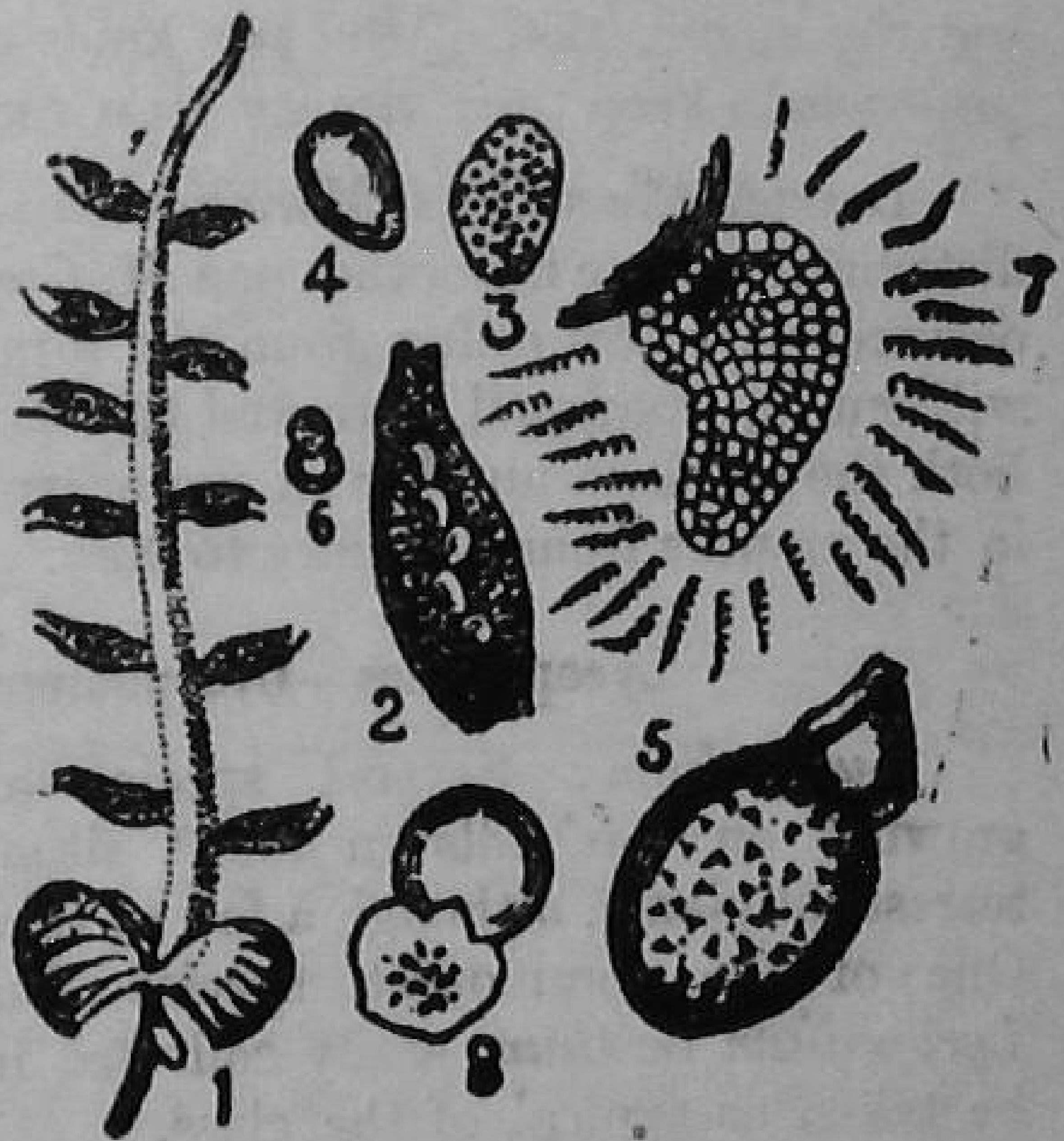

Fig. 335. Sporocarp, sporangia and spores of *Marsilia minuta.* 1 Sporocarp that has germinated. Note the gelatinous stalk bearing the sporangia, now extended. 2. a compartment containing sporangia; 3. a microsporangium; 4. a megasporangium; 5 and 7. germinated megaspores with prothallus and spermatozoids swarming close to the prothallus; 6 and 8. Microspores germinating.

at the base of this pit that the prothallium protrudes. It is into this mucilaginous funnel-shaped pit that spermatozoids get in large numbers to fertilise the egg-cell or ovum. The greater portion of the spore except the lenticular part at its apex is a large nutritive cell full of starch and oil globules. These are used as food-material by the developing prothallus and the embryo is formed in it after fertilisation. The embryo develops into the Marsilia plant which in turn gives rise to the two gametophytes—male and female. Thus there is a regular *alternation of generations* as in the fern plant.

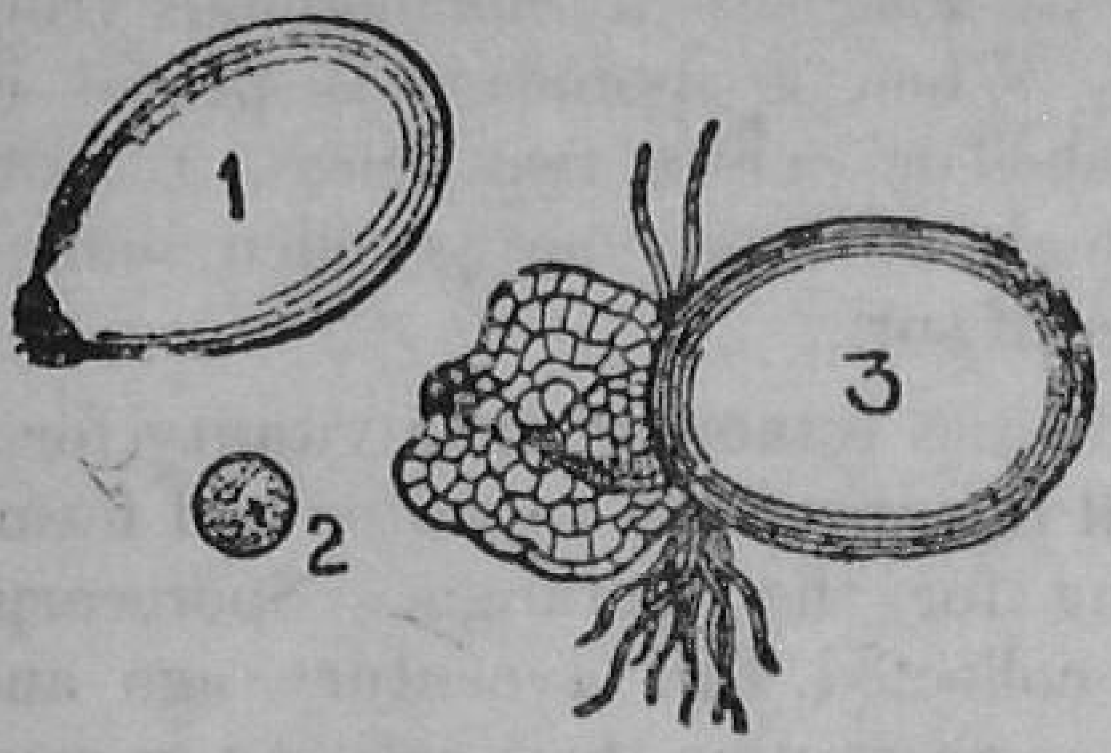

Fig. 336.—Spores of *Marsilia minuta*, 1. megaspore; 2. microspore; 3. megaspore after fertilisation with the embryo formed in it.

The most interesting feature of *Marsilia* is the heterospory and the aggregation of the two kinds of sporangia in hard sporocarps which keep their vitality for a very long time.

Besides the species *Marsilia minuta* which is of very wide distribution there is another one *M. Coromandelica* also of common occurrence. This differs from the former in having larger leaflets without any marginal teeth and the sporocarps also are larger. In both the species a number of sporocarps appear on short petioles in the months from February to May.

Lycopodiales—Lycopodium—Selaginella

Lycopodium:—Several species of Lycopodium are found growing on the hills in moist situations. Many of them are terrestrial plants, although a few of them are pendulous epiphytes. One of the commonest species found in this Presidency is *Lycopodium cernuum* easily collected in the Nilgiris and this may be taken as typical of the class.

Morphology: The plant which represents the sporophyte generation, consists of prostrate stems running for considerable distances either on the surface amidst rotting leaves and humus, or beneath the soil, and numerous secondary branches growing erect, some of which terminating in sporiferous spikes or cones. The primary as well as the secondary branches are all clothed with small narrow leaves. The stem branches in a dichotomous manner, and branches are never axillary.

Roots spring from the prostrate stems and they al.. branch dichotomously after penetrating the soil.

The growing point of the stem consists of a number of cells without any separation into distinct embryonic layers. The epidermal cells of the stem contain chloroplasts, and stomata also occur in the epidermis of the leaves and stems. A transverse

Fig. 337.—*Lycopodium cernuum*. Entire plant.

section of the stem shows a central stele surrounded by a fairly broad cortex. A few layers of cells of the cortex lying close to the stele become thick-walled due to lignification. The single layer of cells of the endodermis and the pericycle of two layers of cells are distinctly seen. The xylem in the stele is in the form of flat plates, effecting unions in various ways one with the other. The elements of the xylem are spiral, pitted and scalariform tracheids. The phloem surrounds the xylem. This structure is termed the **protostele.**

Roots arise from the peripheral layers of the stele and come out piercing the cortex. Their internal structure is after the type of the stem. The root-tip consisting of a group of cells is covered by a root-cap.

Reproduction Asexual.—The club-shaped bodies called cones and found terminating the final branches consist of an axils with close-set small leaves, which are, however, slightly larger than those on the axils below. In the axils of each of the leaves of a cone a sporangium is developed, but not in the axils of the leaves in other parts of the stem. Since the leaves of the cone have sporangia they are termed **sporophylls.** In this plant the leaves are thus differentiated into sporophylls or fertile leaves and ordinary sterile leaves. There are a few species of *Lycopodium* in which all the leaves produce sporangia in their axils without any differentiation.

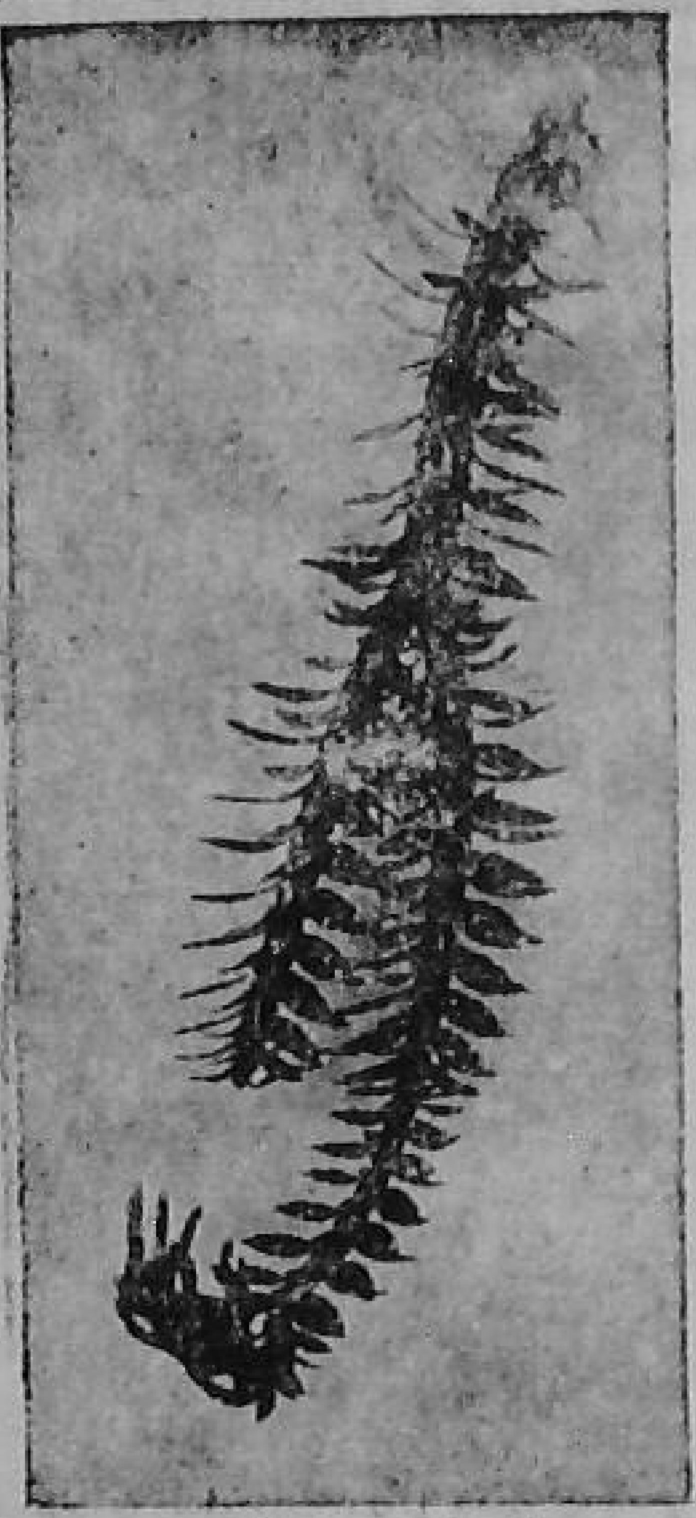

Fig. 338.—An epiphytic pendulous species of *Lycopodium.*

The sporangia produce only one kind of spores and the plant is **homosporous.** The sporangium dehisces into two valves, and sets free the spores which are so small and abundant that they form a very fine powder which is of commercial importance. This Lycopodium-powder is used in coating pills and in pyro-technics. The spore has a reticulated outer coat the exosporium and an inner cellulose coat the endosporium.

Sexual.—The prothallia developing from the spores present a remarkable variation in *Lycopodium.* The prothallus of *L. cernuum* is a cylindrical cushion-like mass of tissue poor in chlorophyll and attached to the soil by rhizoids. Green aerial thalloid lobes are formed in the upper portion of the prothallus. The antheridia and archegonia appear amidst these lobes. All prothallia of Lycopodiums are perennial and have mycorrhiza of fungal hyphæ in their peripheral tissue. The spermatozoids are biciliated.

The spores of Lycopods germinate very tardily, some of them do so only after six or seven years. Prothallia also seem to require a very long time to develop. In some species the prothallus is said to become sexually mature only after twelve to fifteen years.

We thus see that Lycopodiums are distinguished by certain special features. The leaves, which are so conspicuous in Ferns, are in this group very small in size in proportion to the stem. The branching of the stem and root is dichotomous. The

gmaetophyte generation of the prothallium is perennial in all species, and in some it takes over twelve years to form the sexual organs on it. The spores also germinate only after five or more years. The sporangia are produced singly in the axils of leaves. As in the other types there is a regular *alternation of generations.*

Selaginella

Many species of *Selaginella* occur in the plains on the west coast, and on the hills they form a most attractive features of the vegetation of the place. They are grown in gardens on account of their beauty and for their decorative effect. They have usually

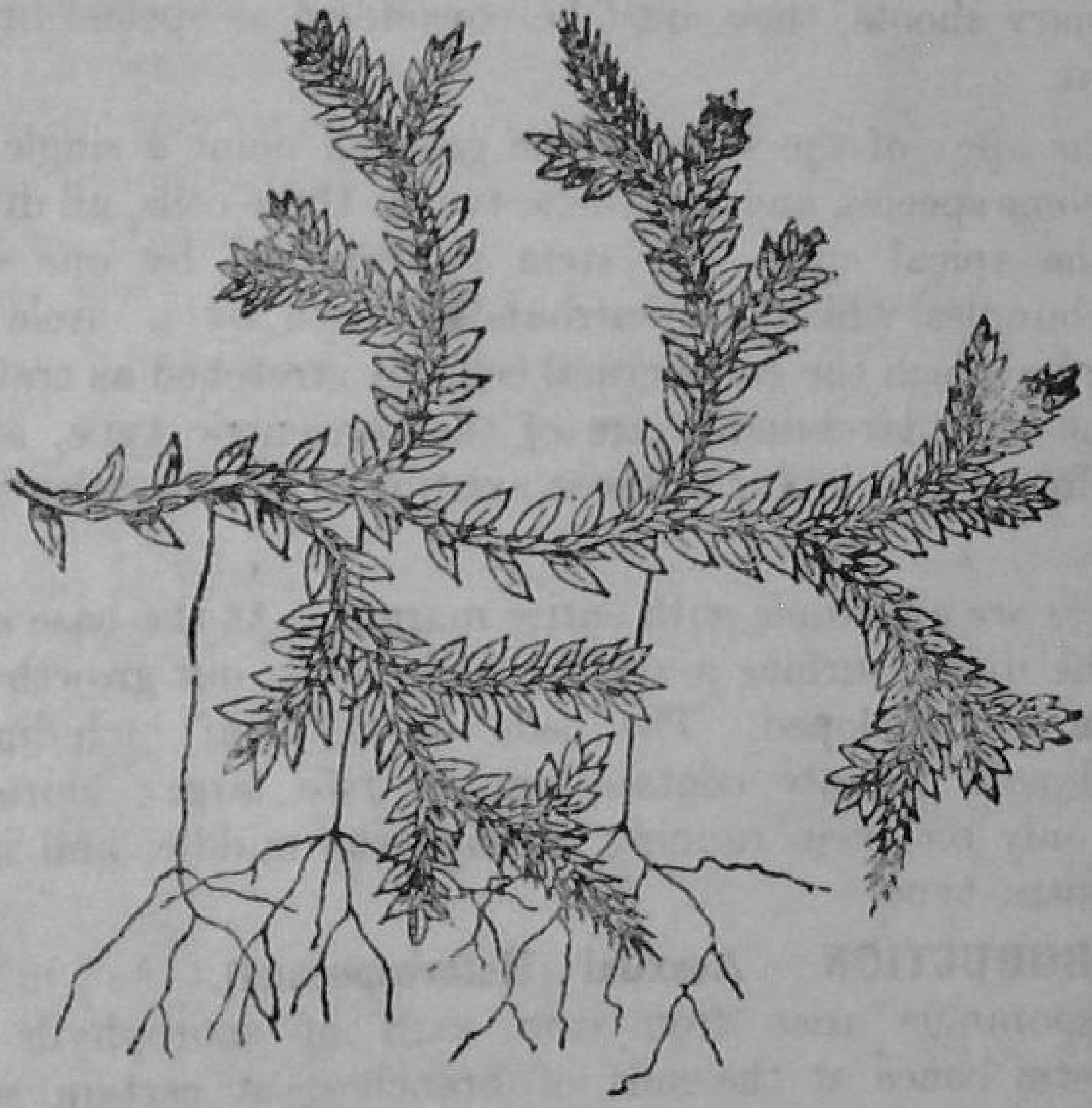

Fig. 339.—*Selaginella plumosa.* Entire plant with rhizophores.

creeping profusely-forked stems, and often form moss-like beds of vegetation. Some are small, others large and climbing and a few are even xerophilous. Selaginellas resemble the Lycopodiums in their habit.

Morphology.—For purposes of study *Selaginella plumosa*, a fairly common species in South India, or *Selaginella inequalifolia*, largely cultivated as an ornamental plant may be chosen. The shoot system of *Selaginella plumosa* consists of stems branching very freely in an apparently dichotomous manner, and all the branches lie more or less in the same plane. Axillary branches do not occur and they develop from lateral buds arising near the apex

of the stem. Since the lateral bud and the apical bud of the stem grow equally well, branching appears to be dichotomous.

The slender stems and branches are clothed with small leaves, which form four rows. Two rows on the upper or dorsal side of the branches consist of small leaves, while the two rows on the ventral side springing from the sides of the branches are somewhat larger. From below the stem where it forks springs a naked greenish white specialised branch named **rhizophore,** and this after penetrating the soil develops roots at its free end. These slender specialised branches arise exogenously and resemble the root in their internal structure. Since rhizophores occasionally develop into ordinary shoots, they must be considered as special branches of the stem.

At the apex of the stem at the growing point a single cell is found in some species, and, in others, two or three cells, all dividing, occupy the apical end. The stem is traversed by one or two vascular bundles which are surrounded, each by a circle of air spaces across which the endodermal cells are stretched as trabecular cells. The vascular bundles are of the concentric type, and the elements found are similar to those existing in the vascular strands of Ferns.

Leaves are all simple with entire margin. At the base of each leaf on the upper surface a small membranous out-growth called the **ligule** is developed. The cells of the leaf including the epidermal cells usually contain one or two large chloroplasts. There is only one vein running through the middle, and it is of the concentric type.

REPRODUCTION :—Asexual (Heterosporous).—As in *Lycopodium*, sporangia arise from the axils of sporophylls which usually form cones at the ends of branches, at certain seasons of the year. All the leaves forming the cone bear sporangia singly in their axils. The *Selaginella* plant being heterosporous, two kinds of sporangia, namely, microsporangia and megasporangia are developed. The former are found in large numbers in the axils of the upper sporophylls, whilst the latter are confined to the axils of a few sporophylls at the basal portion of the cone. Generally only four megaspores are formed, and the microspores are many in a sporangium.

The sporangial wall consists of two layers of cells, and the stalk is a short one.

Sexual.—The microspores are all very small bodies. On germination the spore forms inside it a small prothallial cell and

some peripheral cells enclosing a few cells in the centre which develop into sperms later on. In some of the species of *Selaginella* in which the development of the gametophyte has been observed during the germination of the spores, the peripheral cells get absorbed and the mother cells alone remain. Spermatozoids with two cilia escape by the rupture of the wall of the spore. Compared with the microspores the megaspores are very large. On one side of this spore three radiating ridges are seen and it is here that it bursts. A large amount of reserve material, chiefly in the form of oil, is found inside these spores. The megaspores seem to begin their development in some species within the spo-

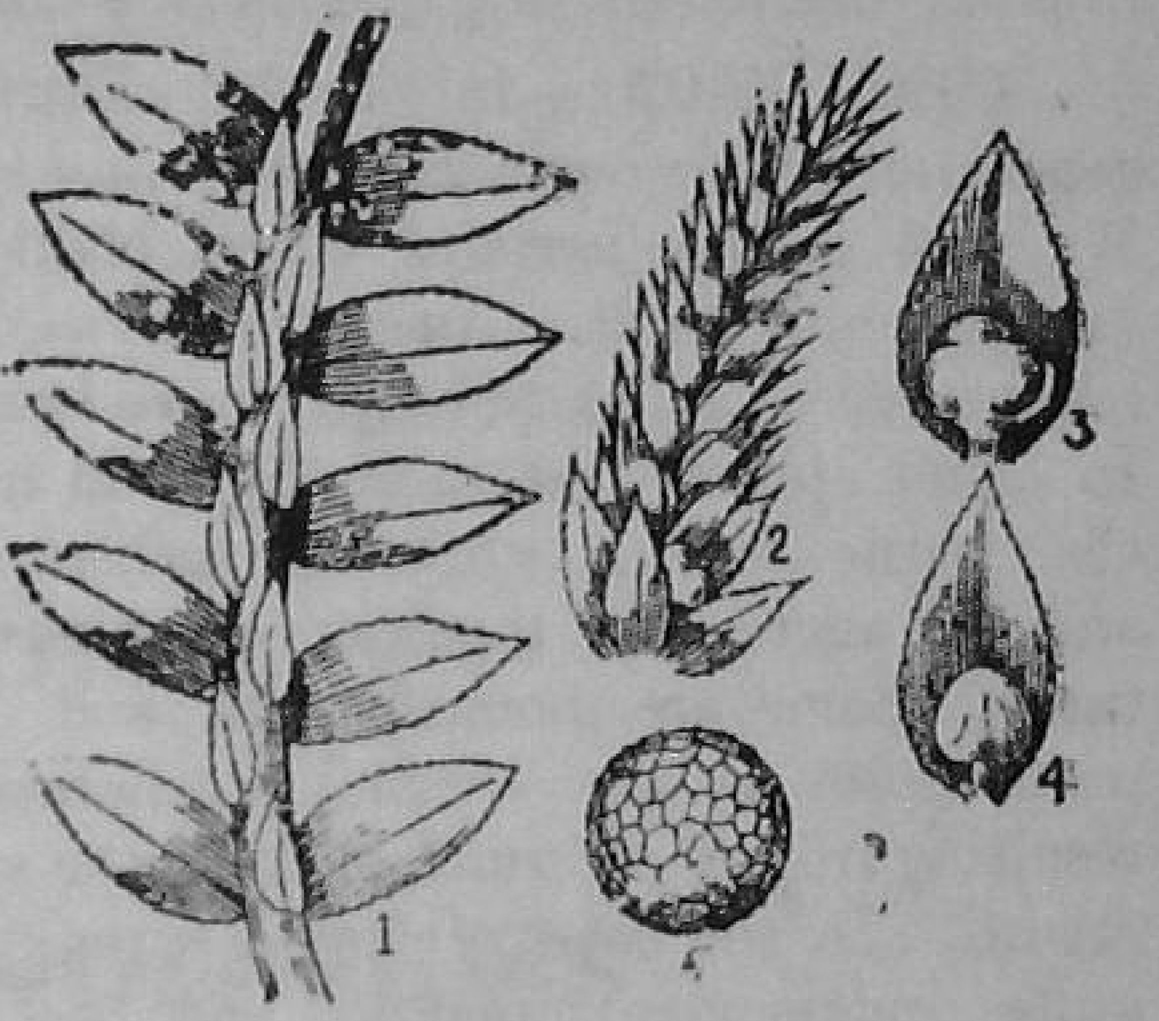

Fig. 340.—*Selaginella plumosa.* a portion of a branch; 2, a cone bearing sporangia in the axis of sporophylls; 3, megasporangium; 4, microsporangium; 5, megaspore; 6, microspore.

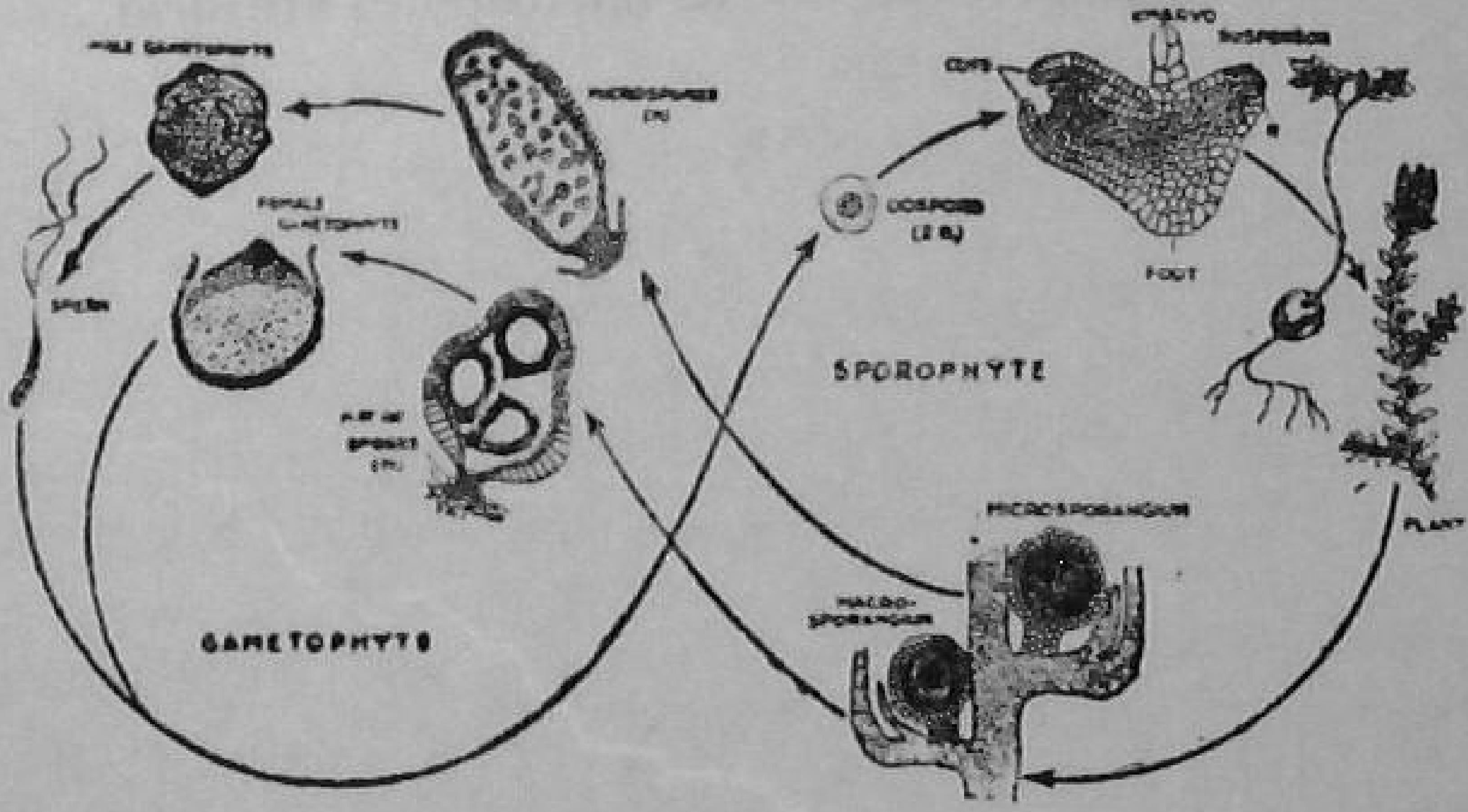

Fig. 341.—Life Cycle—Selaginella

rangia and before escaping from them. By repeated cell division the interior of the spore becomes filled with cells, and these represent the prothallium. The wall of the spore bursts at the place where the three radiating lines are seen and the prothallium protrudes through this opening. Archegonia are formed in the portion of the prothallus protruding through the slit at the top.

Fertilisation is practically similar to that of Ferns. The embryo grows and develops into the sporophyte plant. There is thus an alternation of generations as in the fern and *Lycopodium*.

CONCLUSION:—In all the Pteridophytes the **Sporophyte** generation is independent and shows progressive development. We find in the parts of these plants differentiation of tissues into different kinds. Amongst leaves, most of them are sterile foliage leaves and a few are spore-bearing leaves or sporophylls. In some plants the sporophylis do not materially differ from the sterile leaves, whilst in others they look slighty different and are aggregated together at the extremities of branches as cones. Some are homosporous and others heterosporous. The prothallium is the sexual generation or the **Gametophyte,** resulting from the germination of the spores and bears the sexual organs. In the case of homosporous plants the prothallia are quite independent plants and in heterosporous forms the prothallia develop within the spores and never emerge from them. There is a regular 'alternation of generations.'

Selaginella may be considered to be a form leading from Pteridophyta to seed-plants or **Spermatophyta.** The microspores and megaspores of this plant are homologous respectively with pollen-grains and embryo-sacs. In spermatophyta the pollen grains alone get detached from the sporophyte. In *Selaginella*, on the other hand, megaspores as well as microspores are shed.

SECTION V

GYMNOSPERMS

CHAPTER XXXII

SPERMATOPHYTA

THE Spermatophyta occupy the highest position amongst the types of vegetation. These continue the advance already begun in the sporophytes of Pteridophyta. The alternation of generations so characteristic of the Archegoniatæ is still maintained by the Spermatophyta.

One distinctive feature of this group of plants is the production of the **Seed** as the result of fertilisation. After the formation of the embryo the seed gets separated from its parent plant, the sporophyte. The seed is merely the megasporangium modified to a certain extent. The seed contains the megaspore with the prothallium and the embryo.

The predominance of seed-plants in the Flora of the present day is in itself a clear proof of the success achieved by the Spermatophytes in the struggle for existence. This extraordinary success is due to the further progress attained by the sporophyte over the *Selaginellas*. Like *Selaginella* the seed-plants also produce two kinds of spores, namely, microspores or pollen-grains and megaspores or embryo-sac. But the megaspore **never leaves the sporophyte parent plant.** By this means, protection and proper nutrition to the egg-cell and the embryo are secured.

The Spermatophyta are divided into two classes :—

(1) **Gymnosperms** in which the ovule is **naked, not being enclosed by a carpellary leaf** and (2) **Angiosperms** in which the **ovule has a carpellary protection.**

GYMNOSPERMS

Gymnosperms occupy an intermediate position between Angiosperms and Vascular Cryptogams. These plants do not figure so much in the Flora of the present day. They form but an insignificant portion of the Flora, in spite of their predominance in former times. As a matter of fact, the living representatives of this group appear rather isolated and distinct from one another. This is so as these are survivals of a large class that existed in earlier periods. In South India the only genera of this group that occur in a wild state are *Cycas*, *Podocarpus* and *Gnetum*. Of these, *Podocarpus* is of very local distribution, occurring only in Tinnevelly and Travancore Hills. In Northern India the forests abound

in several species of Gymnosperms such as Pines, Firs, Yews, Spruces, Junipers and Cedars. Some species of *Pinus*, *Cupressus* and *Araucaria* are grown on the hills as ornamental shrubs.

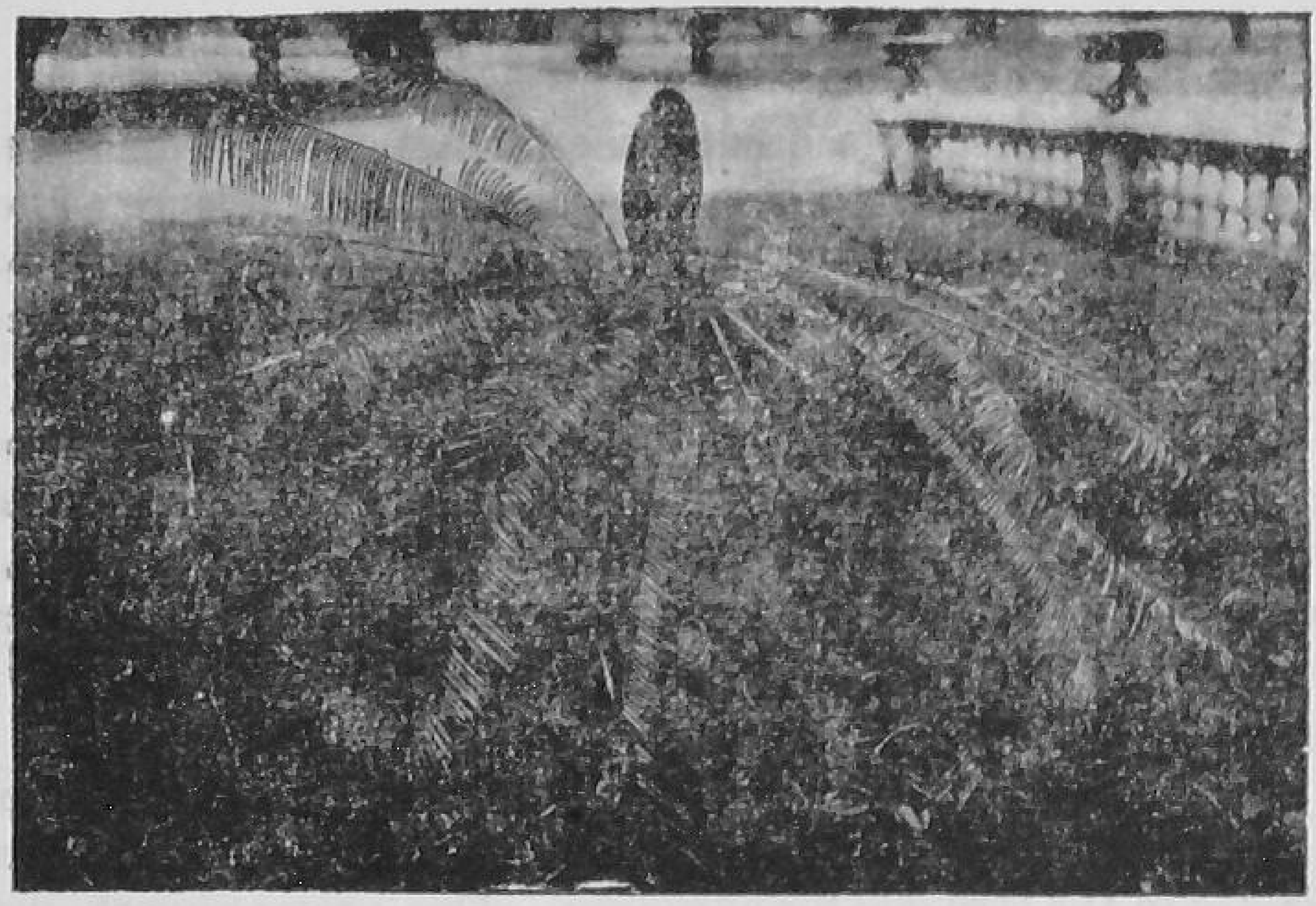

Fig. 342.—Tree of *Cycas circinalis*, with a male cone.

As examples of Gymnosperms we may study the plants *Cycas circinalis*, *Pinus longifolia* and *Pinus excelsa*. The first represents the order Cycadeae and the other two belong to the order Coniferae.

CYCADEAE

The tree *Cycas circinalis*, L., occurs in many gardens as an ornamental plant. It is also met with in a wild state in hilly parts of South India. But it is not abundant anywhere. The tree bears a superficial resemblance to the palms and is like the Tree-Ferns in many respects.

Its stem is erect, usually unbranched, thick, with its exterior covered by the leaf-bases and scales.

This tree bears at its summit a crown of leaves which persists for a year or two, and is then replaced periodically by successive crowns of leaves. There are two kinds of leaves, namely, the **foliage leaves** and the **scale-leaves.** As soon as a rosette of foliage leaves is formed and the leaves are fully expanded, the terminal bud of the stem is visible and it is enveloped in scale-leaves. Within this bud and under the protection of these scale-leaves the next set of foliage leaves develops rather slowly. Thus we see

that at the summit of the tree one set of foliage leaves is separated from the succeeding set by a succession of scale-leaves. The

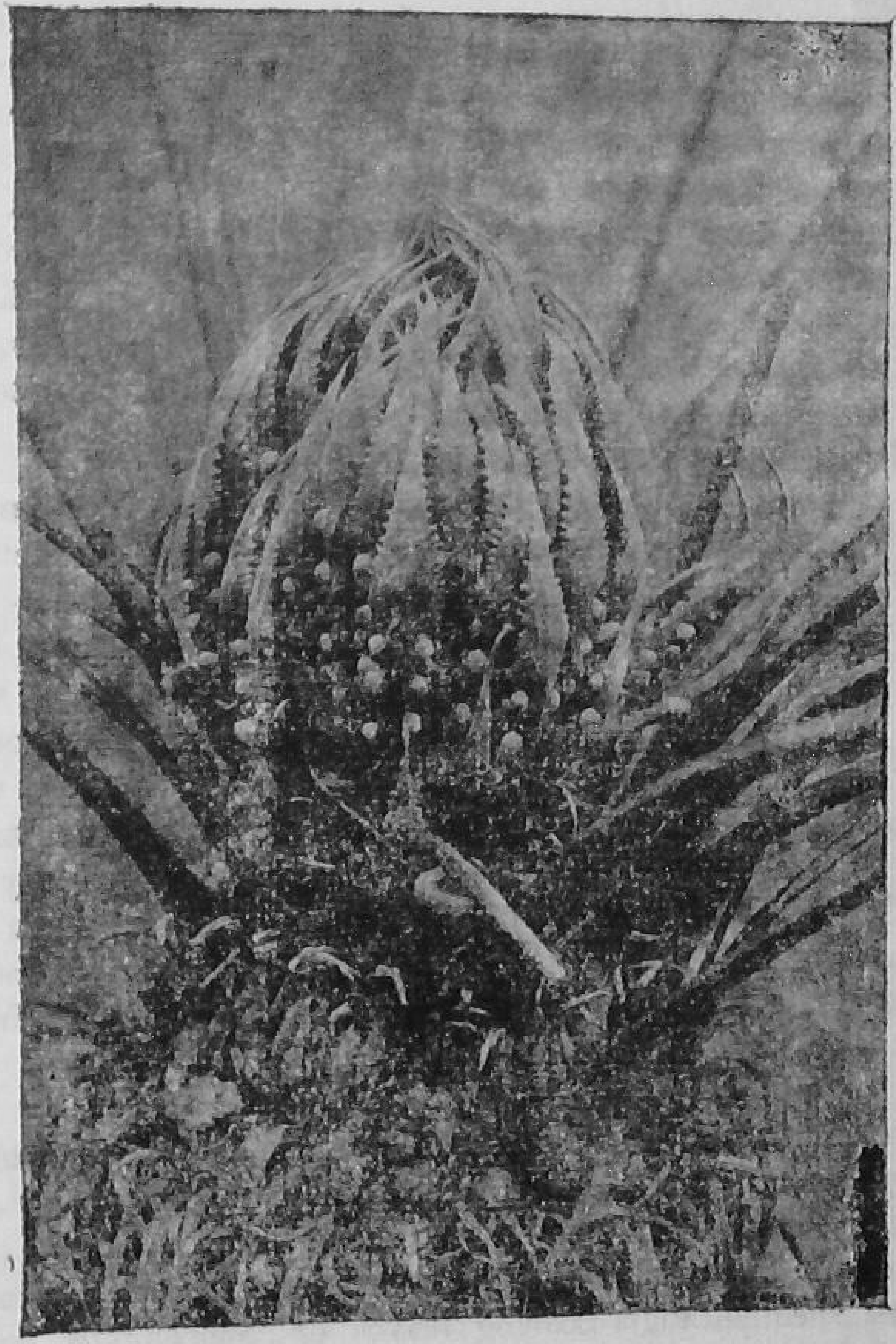

Fig. 343.—Female cone of *Cycas circinalis*, L.

group of foliage leaves, enveloped by the scale-leaves in the terminal bud, takes a year or two to develop and unfold itself as the next rosette of leaves. The scale-leaves are very much smaller than the foliage leaves, but are more in number.

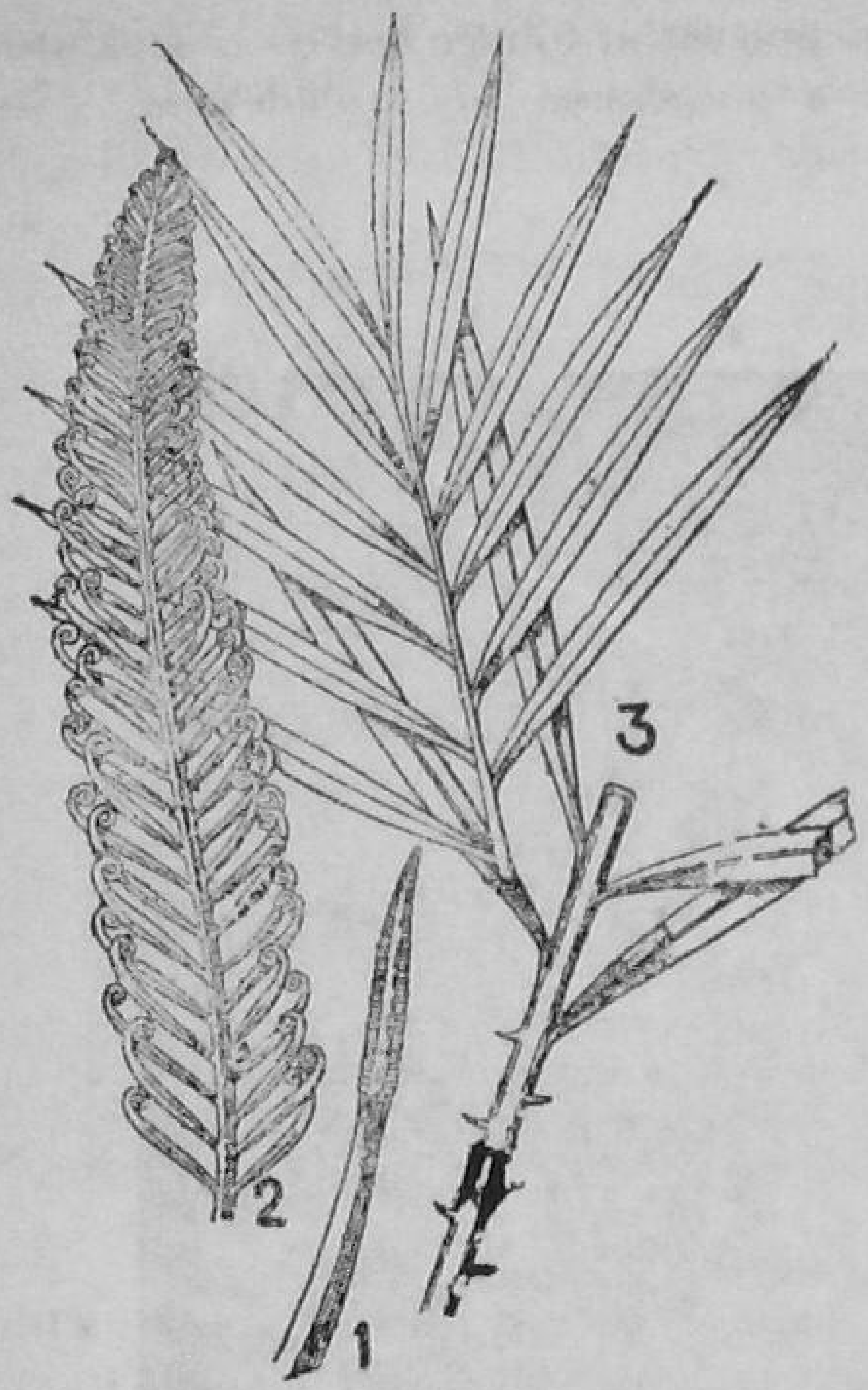

Fig. 344.—*Cycas circinalis*, L. 1. very young leaf; 2, a young leaf just unfolding; 3. the basal 4 and apical portions of a mature leaf.

The foliage leaves are long, varying in length from four to eight feet. They are compound, simply pinnate with a strong midrib and a leaf-stalk of about a foot and a half, which bears short distant spines to almost near the base of the blade. The pinnae are long, linear, one-nerved, thick, green, shining and about quarter of an inch broad. In young leaves the leaflets are folded circinnately as in Ferns.

Stem—Morphology :—In internal structure the stem resembles in essential respects the stem of Angiosperms. The vascular bundles are of the collateral type, but the vascular elements are **tracheids.** There is **secondary thickening.** There is a distinct differentiation of the fundamental tissue into the cortex and medulla, separated from the cortex by a woody cylinder.

Reproduction :—Two kinds of spores, the **microspores** and **megaspores** are produced on different plants. In other words the tree is dioecious. The tree bearing the microsporangia is the male tree and the one producing the megasporangia is the female tree. Further the sporangia-bearing leaves or **Sporophylls** are quite distinct from sterile foliage leaves. The microspores or pollen-grains, as they are termed in Spermatophyta, are formed in unilocular anthers aggregated into groups of three to five on the lower surfaces of brownish leathery scales that are closely aggregated, so as to form a cylindrical ovoid body or cone. These cones are usually found at the apex of the tree and when fully mature are a foot or two long. The antheriferous scales are microsporophylls. (*See* Fig. 345).

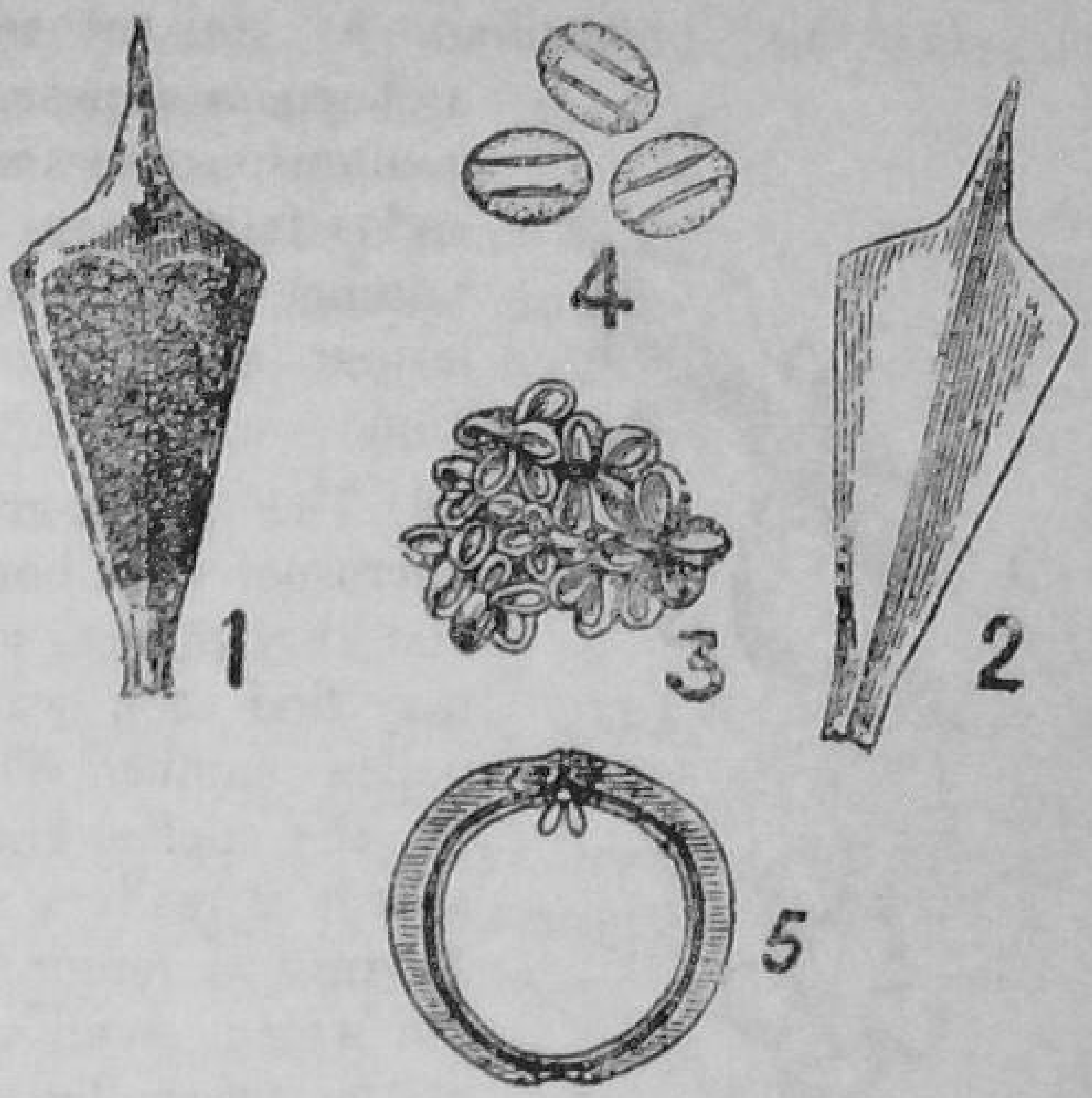

Fig. 345.—Antheriferous scales and ovule of *Cycas circinalis*, L. 1 and 2, antheriferous scales, front and back views; 3. anthers; 4. pollen-grains; 5. ovule cut longitudinally, showing the endosperm, archegonia and the integument.

The female tree bears megasporophylls containing ovules. The megasporophyll is somewhat larger than the microsporophyll and when fully mature it is about a foot long. The upper end of the sporophyll bears a small number of short leaflets, but in the lower portion, in the place of leaflets there are ovules. These ovules grow to a fairly large size even before fertilisation. The megasporophylls resemble the foliage leaf in structure and form to a certain extent but are much smaller than the foliage leaves. (*See* Fig. 346). The megasporophylls occur in groups at the summit of the stem, but not in the form of compact cones. They surround the growing point of the stem. In each sporophyll there are three to five pairs of ovules. The structure of the ovules is simpler than that of the Angiosperms. The *Cycas* ovule consists of a **Nucellus** invested by only a single integument. The nucellus is really the sporangium and the integument is an outgrowth covering the nucellus. There is also a micropyle in the integument leading to the nucellus. Just above the nucellus there is a distinct cavity spacious enough for the lodging of a few pollen-grains and this cavity is called the **pollen-chamber.** The nucellus has in it an embryo-sac which corresponds to the megaspore. Inside the embryo-sac the **endosperm** is formed long before fertilisation. This is really the female gametophyte or

prothallium. In this prothallium at its top two or three archegonia appear. The archegonium possesses a short neck and a fairly large venter containing a large egg-cell, the largest in the vegetable kingdom.

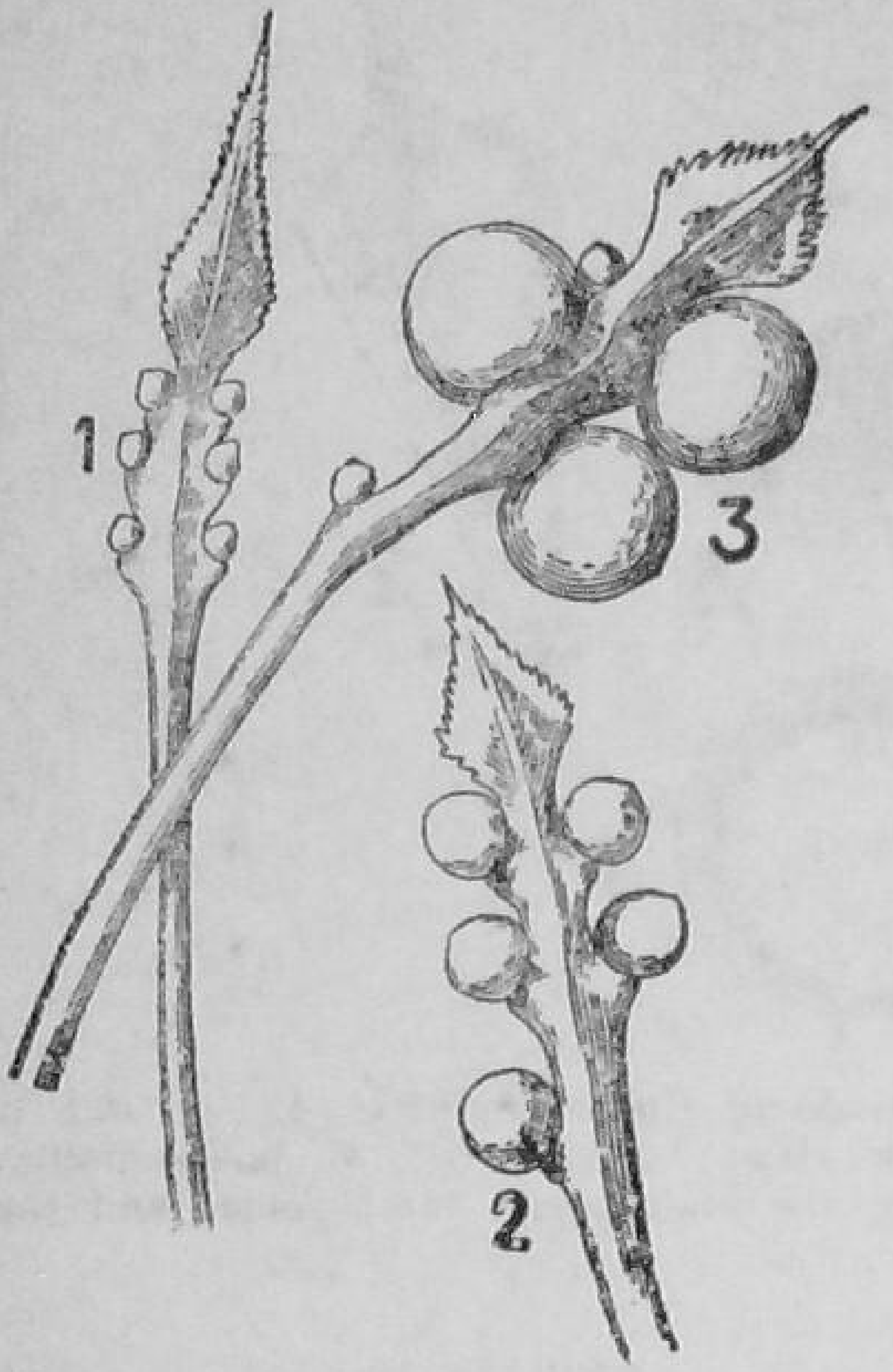

Fig. 346.—Megasporophylls of *Cycas circinalis*. 1, young megasporophyll; 2 and 3. older megasporophylls.

The pollen-grains or the microspores are borne by wind and by chance some grains may find their way into the pollen-chamber. The structure of the pollen-grain betrays that it is really a microspore. There is a single vegetative cell which is all that is left of the prothallium. Another cell, lying close to this prothallus cell and called the spermatogenous cell gives rise to the **male gametes** or **spermatozoids.** The pollen-grain germinates and forms a tube which absorbs food from the remnants of the nucellus. In addition to these absorbing tubes, other tubes larger than these arise from the pollen-grains and these tubes carry the generative cell further down into the pollen-chamber. The generative cell passes down to the extremity of the tube and becomes divided into two spermatozoids. The spermatozoids are interesting bodies. They bear a large number of cilia and so they are capable of movement. (*See* Fig. 347). As soon as the pollen-tube reaches the archegonium it empties its watery contents. The spermatozoids get into the archegonium by moving through this water. Afterwards fertilisation is effected and the embryo is formed.

Cycads are the simplest and the lowest type of all the living Spermatophyta. The plant produces naked seeds without developing a cone or flower. While it possesses certain characteristics peculiar to the seed plants in many respects it resembles the Pteridophyta. The formation of multiciliate spermatozoids, the development of the gametophyte within the megaspore, the circinnate vernation of the leaflets and the presence of sporophylls show the relationship of the *Cycas* to the heterosporous

Vascular Cryptogams. The development of the **seed** and the gametophyte remaining attached to the sporophyte, being enclosed in the megaspore until the formation of the embryo, are forward steps towards Spermatophytes. The presence of the pollen-chamber below the micropyle is a special character of the Gymnosperms.

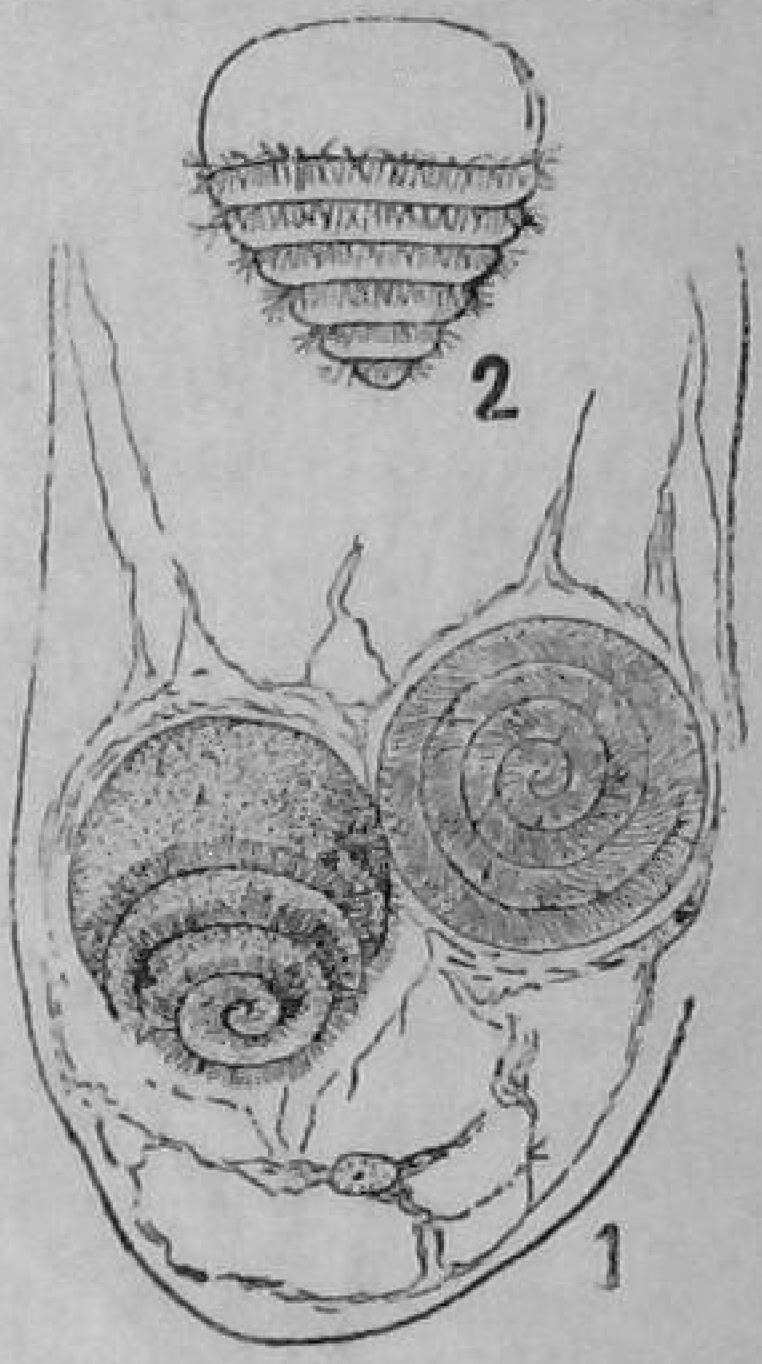

Fig. 347.—Sperm-cells of *Cycas revoluta*. 1. pollen tube, with two sperm-cells ; 2. side view of a spermatozoid or sperm-cell. (After Ikeno and Coulter.)

CONIFERAE.

Types.—The two Pines, *Pinus longifolia*, Roxb and *Pinus excelsa.*, Wall, both belonging to the order Coniferae, are grown as ornamental trees in parks in the hill stations in South India. They are lofty trees somewhat symmetrical and with a characteristic pyramidal shape. The main stem is quite straight and it can be traced from the ground to the top of the tree. This is possible because the apical growing point usually remains intact and it is capable of indefinite growth. Numerous lateral branches are formed and each of them retains its apical bud which grows indefinitely. The lower branches are longer than the upper, and they get gradually shorter towards the top of the tree, thus giving the shoot as a whole the pyramidal shape.

Morphology.—In *Pinus* we have two kinds of branches, namely, long branches that are completely covered by brown scale like leaves and spurshoots or dwarf branches growing out from the axils of the brown membranous scale-leaves. As the number of axillary buds capable of growth is very much limited compared with Angiosperns, the dwarf shoots are numerous. Each spur-shoot has at its apex a cluster of needle-shaped green leaves. In *Pinus longifolia* the cluster consists of three leaves and in *Pinus excelsa* the dwarf shoot bears five to eight leaves in each cluster.

Leaves are of two kinds, namely, the scale leaves borne by the long branches and the foliage leaves found at the ends of spur shoots. The base of the cluster of leaves is always sheathed by thin membranous scales of the terminal bud of the dwarf branch.

Pine leaves persist on the tree for several years. Therefore, this tree is never bare of leaves, although each year some of the older

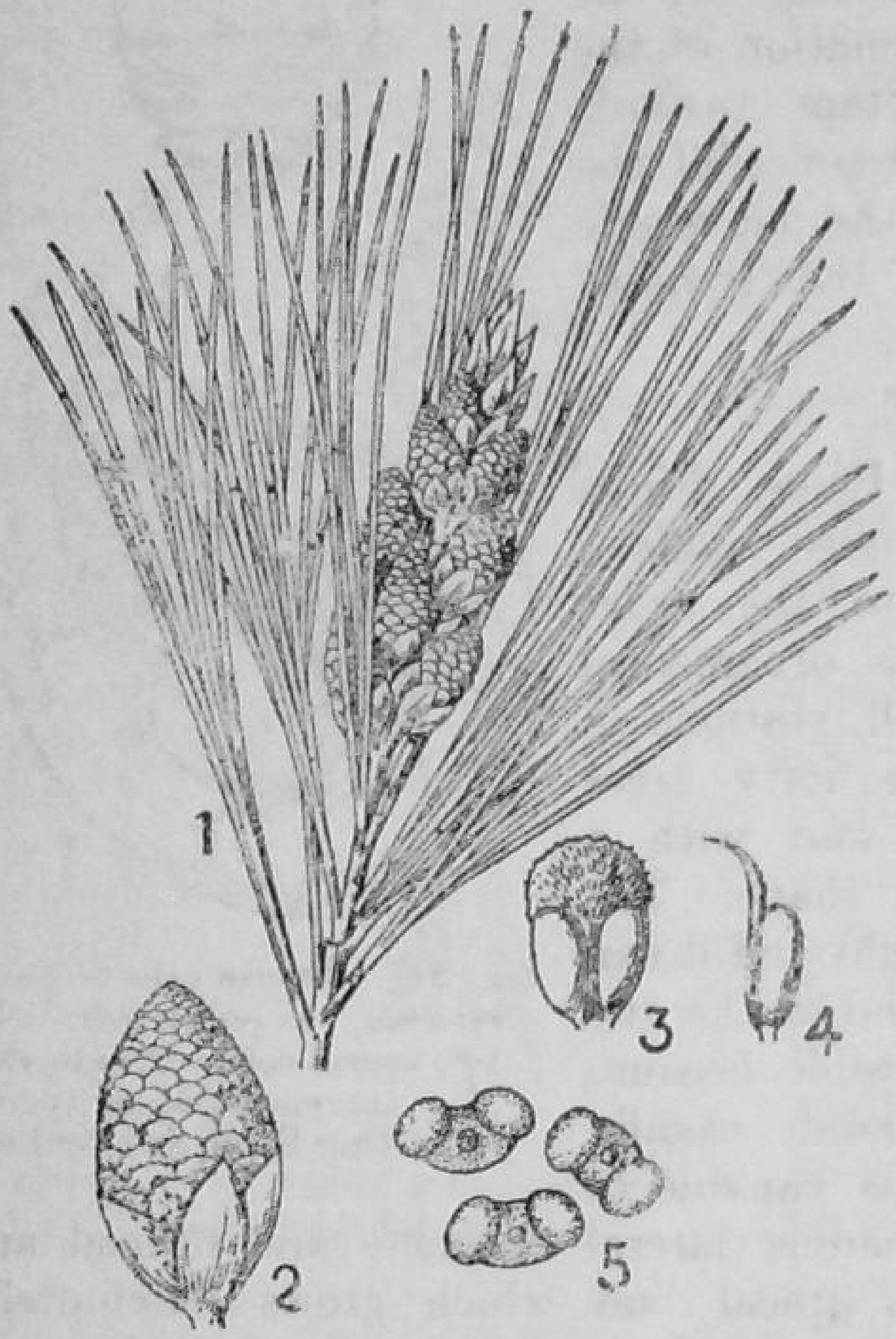

Fig. 348.—*Pinus excelsa.* Wall. 1. branch with leaves and male cones; 2. a male cone; 3 and 4. staminal scales; 5. pollen grains.

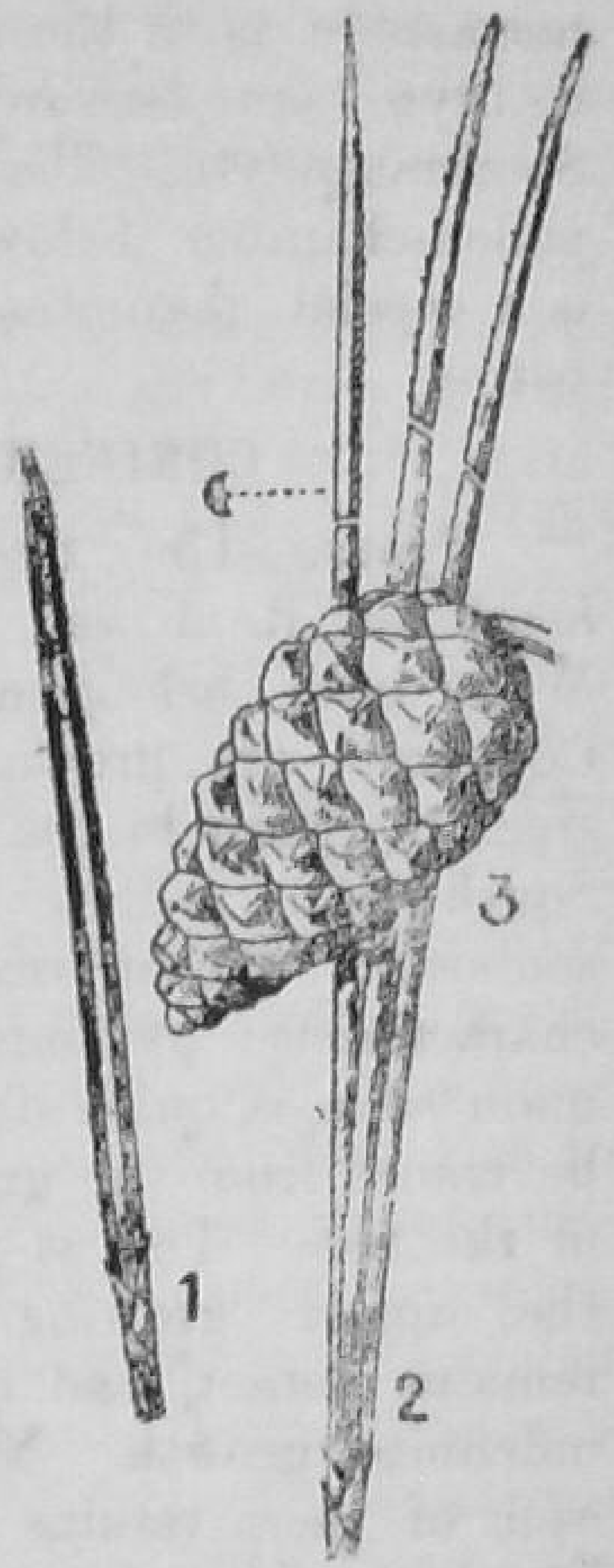

Fig. 349.—*Pinus longifolia,* Roxb. 1 and 2. leaves 3. female cone.

leaves drop off. With the fall of the cluster of leaves, the spur-shoots dry up.

Reproduction :—As regards the reproductive bodies, pollen-grains and ovules, both are borne as in *Cycas* by sporophylls. But the Pines are monoecious. Consequently both the megasporophylls and microsporophylls are found on the same tree, though they are separately borne as male and female **cones.** The male or staminate cones occur in clusters. Each male cone is a cylindrical body, about half an inch long, consisting of a central axis bearing antheriferous scales in spirals. Each scale bears on its lower side two **anthers or sporangia.**

The female cones usually occur singly and not usually in clusters. Like the male sporophylls, the megasporophylls also

are borne spirally on a central axis, the whole structure forming a **cone**. Each megasporophyll bears two ovules on the upper side towards the base.

The pollen-grains are rather peculiar bodies. They are provided with two air-sacs, one on each side of a grain. In a fully mature pollen-grain, we can make out four cells distinctly. They are two prothallial cells, a tube cell and the mother-cell of the antheridium. The two prothallial cells are not always clear, sometimes disorganised remnants only being visible.

The megasporophyll has two ovules. Each of these ovule-bearing scales is believed to be two sporophylls fused together. The ovule consists of the nucellus invested by an integument. At the apex of the ovule there is a micropyle, leading to a cavity below, the pollen-chamber. Within the nucellus the endosperm is formed and a remnant of the nucellus persists at the top near the pollen-chamber. The endosperm corresponds to the gametophyte or prothallium formed in the megaspore of *Selaginella.*

Pollen is produced in abundance. The air-sacs facilitate the floating of the pollen-grains in large numbers in the air. Consequently some of them get into the female cones and reach the pollen-chambers at the base of the micropyle. When the female cones are ready for pollination the scales gape open. In this case pollination is really the lodging of the pollen-grains in the pollen-chamber. After pollination the scales close up without leaving any passage.

The pollen-grain germinates in the pollen-chamber, and forms a tube at first with which it absorbs food material from the remnants of the nucellus. Later on another large tube is formed which goes deeper into the pollen-chamber. At this stage there are only two cells in the grain, namely, the mother-cell of the antheridium and the tube-cell. The tube-cell descends to the end of the pollen-tube, and the other cell, the mother-cell divides into a stalk-cell and a generative cell. While these changes are going on, there will be formed in the prothallial tissue or endosperm of the ovule four or five archegonia. The pollen-tube reaches the archegonium, and by bursting, pours in its contents; and the generative cell has by this time divided into two germ cells. One of the germ-cells, now reduced to a nucleus, fuses with the egg-cell in the archegonium. After this fusion the embryo is formed.

Soon after the lodging of the pollen-grains in the pollen-chamber, the micropyle closes by the growth of the integument in thickness, and the scales begin to grow and close up. In some

species of Pines the scales secrete a resinous substance, which forms an effective barrier for water. The cones increase in size very much after fertilisation. The process of pollen germination and fertilisation are of longer duration in Pines than in other seed-plants. The formation of the seed and the ripening of the cones are also prolonged for nearly a year.

Amongst Gymnosperms the Pines and other species of Conifers are higher forms and they approach the Angiosperms in several respects. In the anatomical structure of stems and roots, there is a great resemblance between Angiosperms and Conifers, at any rate in all essential features. The only difference appears to be that the elements of xylem are all tracheids and not trachea.

SECTION VI

TAXONOMY
OR
SYSTEMATIC BOTANY

SECTION VII

GENETICS

CHAPTER XXXIII

TAXONOMY OR SYSTEMATIC BOTANY

ORDERLINESS is a very important feature of Science. So the plants of the world must each be given a place in a system which must be reasonable in the light of modern Science and therefore acceptable to everybody. When such an arrangement of plants which will satisfy everybody is found, then it becomes very useful for the identification of plants on which is dependent the progress of various sciences such as Forestry, Agriculture, Medicine and the various industrial sciences, etc., where a correct knowledge of plants plays a tremendous part.

The ideal classification should be one which is based on blood relationship—spoken of as AFFINITY. It should be also fairly easy and practicable. Evidences of Evolution point out clearly that from simple forms of plant life, complex and better organised forms have evolved and that all these are clearly related.

In Taxonomy the term category refers to any group such as genera, species, families, etc. Binomial nomenclature is more common. Trinomial nomenclature is used only in special cases where it is a necessity as, for example, *Puccinia graminis triti* where it denotes the particular strain of the rust which affects the wheat only or in *Ustilago annulati* where the particular smut infects the species *Andropogon annulatus* (now known as *Dicanthium annulatus*).

Development of Systems of Taxonomy

Nomenclature preceded Taxonomy. The first names were not international. They were common names in many languages and tongues.

Before 1859, the date of publication of Darwin's "Origin of Species" and the introduction of the idea of evolution, there was no good system of classification.

The Greeks were the fathers of the Systematic and Medical Botany of to-day. Aristotle and, particularly his pupil, Theophrastus, have been called the fathers of Botany. His "Enquiry into Plants", an English translation of which has been made, shows the comparatively vast knowledge for that period that he possessed about Botany.

The pioneers, the Greeks, paid far too much attention to the vegetative parts of plants (roots, stem and leaf) which we know change with the environment and they also made far too much speculation—philosophizing.

For some period after the Greeks there was a lull and the 16th century saw a revival of the science. An Italian Caesalpini did some valuable work but this lacked a consistent morphological basis and so little of it has survived. In Central Europe, particularly in Holland and Germany, much progress was made during the 16th century. Certain groups, such as Leguminosae, Gramineae, Compositae, Labiatae, etc., were formed. The following are the notable works of this period—*Illustrated Herbals of Bronfels* (1530), and the descriptive *Materia Medica of Book* (*Tragus 1530*) G. Bauching wrote an introduction to Botany in 1620 where 6,000 species were described and he used the binomial nomenclature. The strength of the work of all these people lay in their numerous and closely comparative observations and in the predominance of morphological characters over economic distinctions.

The botanists of Western Europe—of England and France—followed the morphological method to the exclusion of philosophy and economic usage. John Ray published his *History of Plants* in 1704 and his system of classification had anticipated to a certain extent the modern systems.

C. Linnaeus, a native of Sweden, was one of the foremost botanists of the day; he travelled all over Europe and made a very wide study of the European flora and published his famous system of classification—the LINNAEAN SYSTEM in 1735. This system is now recognised to be a very artificial one and therefore of no use to us. But it has to be said to the credit of Linnaeus

that no better system than this existed then and Linnaeus used the binomial nomenclature very freely. His *Species Plantarum* (1753) and his "*Genera Plantarum*" (1754) stand to-day as classic works in Botany.

A. L. De Jussieu who lived in the later part of the 18th century was a French man of no ordinary capacity. He may be said to be the founder of the present system of taxonomy. Jussieu avoided giving undue importance to terms like woody and herbaceous and laid more emphasis on more important parts, namely, cotyledons, petals and stamens.

Later, discoveries were made such as that of Robert Brown on seeds including nature of the endosperm and the lack of carpellate covering for ovules in Gymnosperms, Endlicher's anatomical studies and Hofmeister's embryological studies and the making out of the alternation of generations, etc.

These helped those who followed namely, A. P. De Candolle, Bentham and Hooker, Eichler, etc. who improved on Jussieu's system. Bentham and Hooker, two great English systematists, published their "*General Plantarum*" (1862—1883). The system of classification as drawn by them is one of the best and widely followed in the British Empire. They made a rather complete series of categories giving Dicotyledons, Monocotyledons and Gymnosperms equal rank. The Dicotyledons were divided into 3 sub-classes, the further sequence of categories being series, cohort, order, genus and species.

Julius von Sachs (1882) proposed a classification for lower plants which is as famous as that of Bentham and Hooker's for the higher plants.

Engler and Prantl, two German Botanists (1887—1909) published "*Die Nature ichan Pflazenfamilien.*" It is practically followed all over Europe. Its value lies in its broad treatment of the entire plant kingdom, its excellent illustrations and its phylogenetic arrangement of many groups.

The latest is that of J. Hutchinson of Kew which is also one of the best.

As an illustration we shall consider certain definite plants and their classification. The common okra or Lady's Finger is called *Hibiscus esculentus*, L. All okra plants, wherever they may be, are grown from seeds of a previous generation. The offspring resemble the parents in many respects and so we recognise them as forming a species. Similarly we have the SPECIES *Hibiscus micranthus*, *Hibiscus rosa-sinensis* and *Hibiscus vitifolius*. On comparison

we find that all these species possess certain characters in common and they are the following :—The calyx is gamosepalous with a whorl of bracts at its base ; there are five petals twisted and adherent at the base to the staminal column ; the stamens form a monadelphous tube with unilocular anthers, enclosing a superior ovary and a filiform style which ends in five stigmatiferous branches. These are the characters of a GENUS and the name of the genus is *Hibiscus*.

If we compare the various species of *Hibiscus* with the plants Portia tree and *Abutilon indicum*, we can trace certain similarities between them in some respects. In all these plants the calyx is monosepalous, petals contorted and adnate with the staminal tube at the base ; the stamens monadelphous forming a tube and the anthers unilocular—These characters are enough to constitute the FAMILY Malvaceae. We may set forth these facts in a tabular form and show the limits of the Species, Genus and the Family.

Plants with gamosepalous calyx, free contorted petals adherent at the base with the staminal tube and anthers unilocular .. .. .. *Malvaceae*.

Plants of this Family may be divided into Genera and Species as detailed below by taking the examples mentioned above.

Style not branched at the free end .. *Thespesia*.
Style branched at the free end ..
  Epicalyx not present—
    Style branches and carpels more than twenty .. .. *Abutilon*.
  Epicalyx present—
    Style branches and carpels five .. *Hibiscus*.

Species of the genus Hibiscus.

Flowers small.
  Petals white—
    Fruits small round ; seeds cottony. *H. micranthus*.
Flowers large.
  Petals red—
    Fruit not developed .. .. *H. rosa-sinensis*.
  Petals yellow—
  Fruit short.
    Fruit naked and angled .. *H. vitifolius*.
    Fruit covered with close-set bristles. *H. cannabinus*.
  Fruit long.
    Calyx spathaceous .. .. *H. esculentus*.

Angiosperms—Classification of Families dealt with in the Text according to Bentham and Hooker's System (1862—1883).

CLASS	SUB-CLASS	FAMILIES
I. *Dicotyledons.*	I. POLYPETALAE Flowers complete, Corolla polypetalous.	SERIES I—*Thalamiflorae.* 1. Anonaceae. 2. Nymphaceae. 3. Crucifereae. 4. Cappárideae. 5. Malvaceae. 6. Sterculiaceae. 7. Tiliaceae. SERIES II—*Disciflorae* 8. Rutaceae. 9. Meliaceae. 10. Rhamneae. 11. Ampelideae or Vitaceae. 12. Sapindaceae. 13. Anacardiaceae. SERIES III—*Calyciflorae.* 14. Leguminosae. 15. Rosaceae. 16. Combretaceae. 17. Myrtaceae. 18. Cucurbitaceae. 19. Aizoaceae or Ficoideae. 20. Umbelliferae.

Angiosperms—Classification of Families dealt with in the Text according to Bentham and Hooker's System (1862—1883)—(*contd*)

Class	Sub-class	Families
1. *Dicotyledons*—contd.	2. Gamopetalae	Series I—*Inferae*
	Flowers complete, corolla gamopetalous.	21. Rubiaceae. 22. Compositae.
		Series II—*Heteromerae.*
		23. Sapotaceae. 24. Oleaceae. 25. Apocynaceae. 26. Asclepiadaceae. 27. Boragineae. 28. Convolvulaceae. 29. Solanaceae. 30. Scrophularineae. 31. Bignoniaceae. 32. Acanthaceae. 33. Verbenaceae. 34. Labiatae.
	3. Incompletae	Series I—*Curvembryae.*
	Flowers in-complete, usually unisexual.	35. Amarantaceae.
		Series II—*Micrembryae.*
		36. Piperaceae.

		SERIES III—*Daphnales*
		37. Laurineae.
		SERIES IV—*Achlamydosporeae*
		38. Loranthaceae.
		39. Euphorbiaceae. 40. Urticaceae.
2. *Monocotyledons*	1. MICROSPERMAE Inner series of perianth petaloid, ovary inferior, seeds numerous.	41. Hydrocharitaceae. 42. Orchideae.
	2. EPIGYNAE Flowers with double, usually petaloid perianth ovary usually inferior syncarpous.	43. Scitamineae. 44. Amaryllideae.
	3. CORONARIEAE Flowers with a double usually petaloid perianth, ovary superior, almost always syncarpous.	45. Liliaceae. 46. Commelinaceae.
	4. CALYCINAE Perianth small, endosperm copious.	47. Palmae.
	5. NUDIFLORAE Flowers achlamydeous with a dry scarious perianth; ovary mostly apocarpous.	48. Aroideae.
	6. GLUMALES Flowers small, naked, perianth absent or represented by scales or hairlike structures, ovary always uniovulate.	49. Cyperaceae. 50. Gramineae.

Classification of Families in the Text according to J. Hutchinson of Kew (1925).

Class	Division	Sub-Divisions and Families	
1. *Dicotyledons*	1. ARCHICHLAMYDEAE		
	Petals free from each other or absent, very rarely united at base.	1. Anonales.	1. Anonaceae.
		2. Laurales.	2. Lauraceae.
		3. Ranales.	3. Nymphaeaceae.
		4. Piperales.	4. Piperaceae.
		5. Capparidales.	5. Capparidaceae.
		6. Cruciales.	6. Cruciferae.
		7. Caryophyllales.	7. Aizoaceae (Ficoideae).
		8. Chenopodiales.	8. Amarantaceae.
		9. Cucurbitales.	9. Cucurbitaceae.
		10. Myrtales.	10. Myrtaceae.
		11. Tiliales.	11. Tiliaceae. 12. Sterculiaceae.
		12. Malvales.	13. Malvaceae.
		13. Euphorbiales.	14. Euphorbiaceae.
		14. Rosales.	15. Rosaceae.
		15. Leguminosae.	16. Caesalpiniaceae. 17. Mimosaceae. 18. Papilionaceae.
		16. Urticales. 17. Santalales. 18. Rhamnales.	19. Urticaceae. 20. Loranthaceae. 21. Rhamnaceae. 22. Ampelidacea (Vitacea).

		19. Rutales. 20. Meliales.	23. Rutaceae. 24. Meliaceae.
		21. Sapindales.	25. Sapindaceae. 26. Anacardiaceae.
	2. METACHLAMYDEAE.	22. Umbelliflorae.	27. Umbelliferae.
	Petals united into a tube.	23. Ebenales. 24. Loganiales. 25. Apocynales.	28. Sapotaceae 29. Oleaceae. 30. Apocynaceae.
		26. Rubiales. 27. Asterales.	31. Asclepiadaceae. 32. Rubiaceae. 33. Compositae.
		28. Boraginales. 29. Solanales.	34. Boraginaceae. 35. Solanaceae. 36. Convolvulaceae.
		30. Personales.	37. Scrophulariaceae. 38. Bignoniaceae. 39. Acanthaceae.
		31. Lamiales.	40. Verbenaceae. 41. Labiatae.
2. *Monocotyledons.*	1. CALYCIFERAE.		
	Calyx bearers. Root stock is a rhizome, no bulbs or corms.	1. Butomales. 2. Commelinales.	42. Hydrocharitaceae. 43. Commelinaceae.
		3. Zingiberales.	44. Musaceae. 45. Cannaceae. 46. Zingiberaceae. 47. Marantaceae.

Classification of Families in the Text according to J. Hutchinson of Kew (1925)—(*concld.*)

Class	Division	Sub-Divisions and Families	
Monocotyledons—cont.	2. Corolliferae		
	Petaloid group, Corm and bulb common.	4. Liliales. 5. Arales. 6. Amaryllidales. 7. Palmales. 8. Orchidales.	48. Liliaceae. 49. Araceae. 50. Amaryllidaceae. 51. Palmaceae. 52. Orchidaceae.
	3. Glumiflorae		
	Perianth reduced absent, or represented by lodicules.	9. Cyperales. 10. Graminales.	53. Cyperaceae. 54. Gramineae.

Classification according to the system of Engler and Prantl (1892).

Class	Division	Families.
1. *Monocotyledons*	1. Helobiae.	1. Hydrocharitaceae.
	2. Glumiflorae.	2. Gramineae. 3. Cyperaceae.
	3. Principes.	4. Palmae.
	4. Spathiflorae.	5. Araceae.
	5. Farinosae.	6. Commelinaceae.
	6. Liliflorae.	7. Liliaceae. 8. Amaryllidaceae.
	7. Scitaminae.	9. Musaceae. 10. Cannaceae. 11. Zingiberaceae. 12. Marantaceae.
	8. Microspermae.	13. Orchidaceae.
ledons.	Series I—*Archichlamydeae* Devoid of or with imperfect perinth, petals free from each other.	
	1. Piperales.	1. Piperaceae.
	2. Urticales.	2. Urticaceae.
	3. Santalales.	3. Loranthaceae.
	4. Centrospermae.	4. Amarantaceae. 5. Aizoaceae.
	5. Ranales.	6. Nymphaeaceae. 7. Anonaceae.
	6. Rhoeadales.	8. Cruciferae. 9. Capparidaceae.
	7. Rosales.	10. Rosaceae. 11. Leguminosae.
	8. Geraniales.	12. Rutaceae. 13. Meliaceae. 14. Euphorbiaceae

Classification according to the system of Engler and Prantl (1892)—(*Concld.*)

CLASS	DIVISION	FAMILIES.
	SERIES I—*Archichlamydeae*—cont.	
2. *Dicotyledons.*—cont.	9. Sapindales.	15. Ampelideae. 16. Anacardiaceae. 17. Sapindaceae.
	10. Rhamnales.	18. Rhamnaceae.
	11. Malvales.	19. Tiliaceae. 20. Malvaceae. 21. Sterculiaceae.
	12. Myrtiflorae.	22. Myrtaceae. 23. Combretaceae.
	13. Umbelliflorae.	24. Umbelliferae.
	SERIES II—*Sympetale* Perianth in two whorls, Corolla with few exceptions, gamopetalous, stamens twice as many as the petals or reduced to 4 or 2.	
	14. Ebenales.	25. Sapotaceae.
	15. Contorte.	26. Apocynaceae. 27. Asclepiadaceae. 28. Oleaceae.
	16. Tubiflorae.	29. Convolvulaceae. 30. Boraginaceae. 31. Bignoniaceae. 32. Verbenaceae. 33. Labiatae. 34. Scrophulariaceae. 35. Acanthaceae.
	17. Rubiales.	36. Rubiaceae.
	18. Campanulatae.	37. Cucurbitaceae. 38. Compositae.

1. Anonaceae.

Characters of the family.—Trees, shrubs or climbers with *aromatic wood and leaves: Leaves* alternate, simple, bifarious, exstipulate; *Flowers* bisexual, solitary, fascicled or Umbelled. *Sepals* usually 3, small, thin and valvote; *Petals* 6, in two series of 3 each or 3 (free or partly united.) *Stamens* indefinite, hypogynous, closely and spirally packed on the torus, with short filaments; anther lobes linear, usually crested by the dilated end of the prolonged connective; *Ovary* superior of *indefinite carpels*, usually free, stipitate in fruit; *Fruit* apocarpous or syncarpous and fleshy. *Seeds* with *ruminate endosperm.* (Fig. 350).

2. DISTRIBUTION.—Tropics and sub-tropics.

Types :—*Polyalthia longifolia*, Benth.

Anona squamosa, L.

Polyalthia longifolia is a small, handsome, evergreen tree with straight trunk which branches freely. *Leaves* shining, bifarious, lanceolate with undulate margins, exstipulate, shortly petiolate and studded with pellucid glands. *Flowers* green, in short fascicles or umbels, arising from old branches. *Sepals* small, 3, valvate and triangular. *Petals* 6 in two series of 3 each, valvate, flat and spreading from the base, thin, ovate and elongated at the tip. *Stamens* indefinite, spirally arranged on a prominent convex receptacle, hypogynous and cuneate; *anther* lobes extrorse, concealed by the *dilated end of the connective. Ovary* of free carpels with one or two ovules in each. *Fruit* a number of free one-seeded berries. (*See* figure 351.) *Seed* with ruminated endosperm.

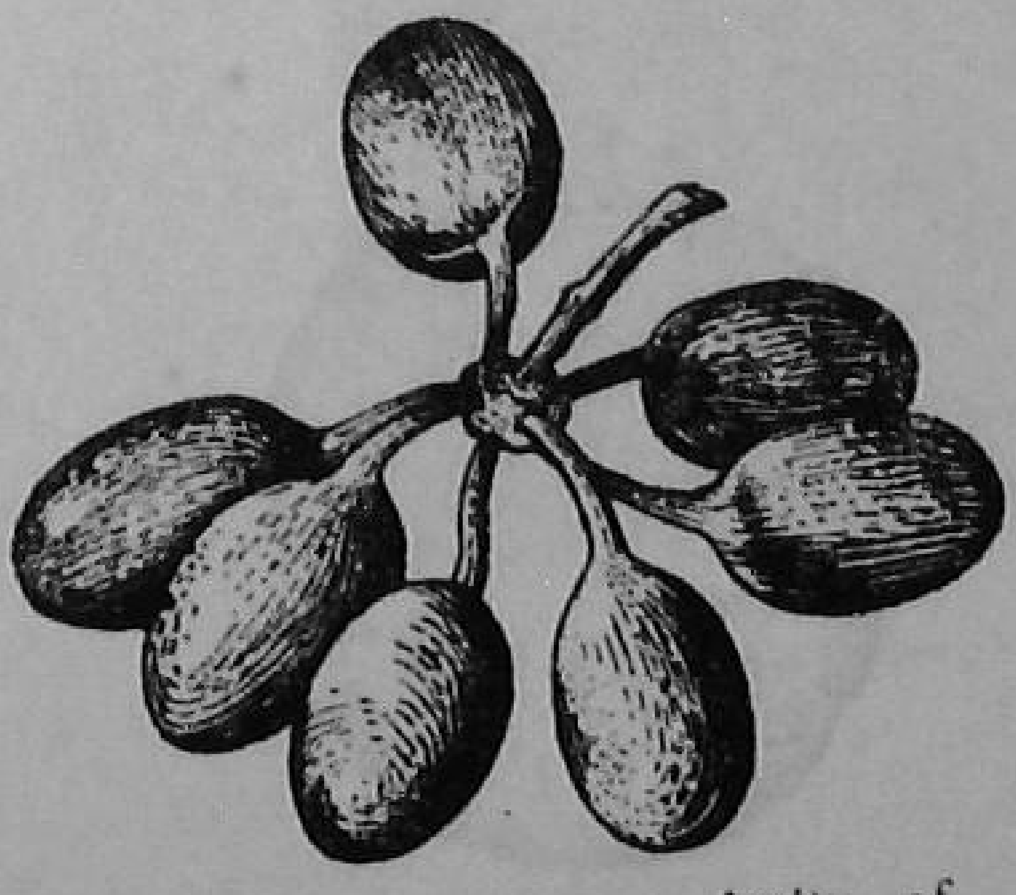

Fig. 350.—Apocarpous fruits of *Polyalthia longifolia.*

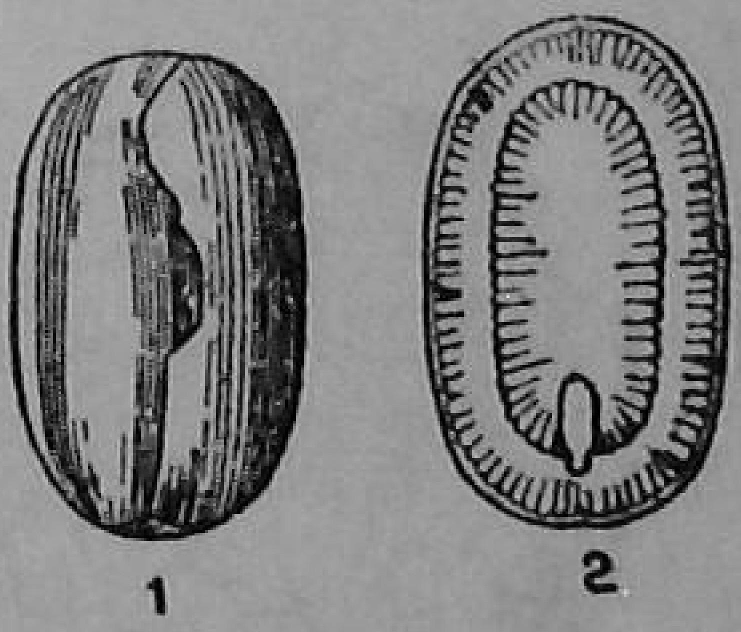

Fig. 351.—Seeds of *Polyalthia longifolia.* 1. entire seed; 2. seed cut longitudinally to show the ruminated endosperm.

Anona squamosa is a small tree with bifariousedly arranged leaves which are simple, alternate, exstipulate, short-stalked, oblong, entire and glaucous beneath. *Flowers* greenish-white, solitary or fascicled. *Sepals* 3 small, membranous and valvate. *Petals* 3 valvate, thick and fleshy, and concave at the base. *Stamens* indefinite, hypogynous, spirally packed on the receptacle; anther-lobes hidden by the *dilated tip of the connective*. *Ovary* superior many-carpelled, syncarpous. *Fruit* fleshy, syncarpous and aggregate.

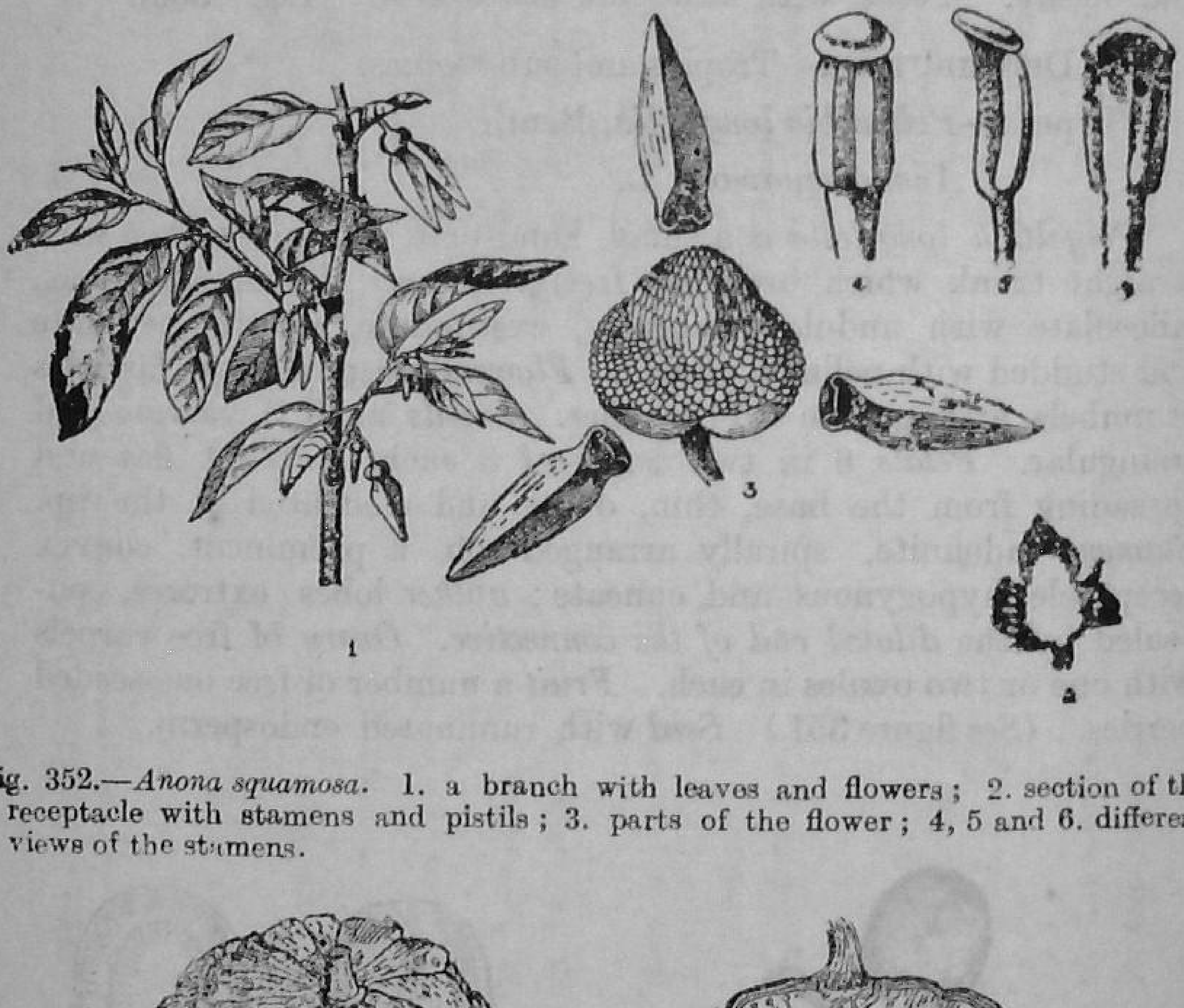

Fig. 352.—*Anona squamosa*. 1. a branch with leaves and flowers; 2. section of the receptacle with stamens and pistils; 3. parts of the flower; 4, 5 and 6. different views of the stamens.

Fig. 353.—*Anona squamosa* 1. entire fruit; 2. fruit cut through.

Useful plants.

(1) *Anona reticulata.*—Bullocks Heart (Ram Sita).

(2) *A. squamosa.*—Custard apple, Sweet sop, Fruit edible (Sita fruit).

(3) *A. Cherimolia*—Cherimoyer.

(4) *Artabotrys odorattisimus.*—flowers frgrant.

(5) *Polyalthia longifolia*—ornamental avenue tree.

(6) *Miliusa velutina*—Wood valuable.

2. Nymphaceae.

Characters of the family.—Aquatic herbs with cordate or rotund large leaves, peltate attached to long petioles. The *leaves* are often floating or raised above water. The stem is underground creeping and laticiferous. *Flowers*—solitary, large, showy and on long petioles; sweet scented: *Sepals* 4-6 free adnate to the torus: *Petals* numerous, hypogynous or perigynous imbricate, sometimes gradually passing into the stamens. *Stamens* indefinite with flat filaments, anthers introrse, longitudinal dehiscence with or without appendages to the connective. *Ovary*-of 8 or more carpels either fused with the receptacle or free and sunk in the torus, ovules 1 to many on the walls or from the apex of the carpel. *Fruit* fleshy and spongy. *Seeds* with both perisperm and endosperm or only with endosperm.

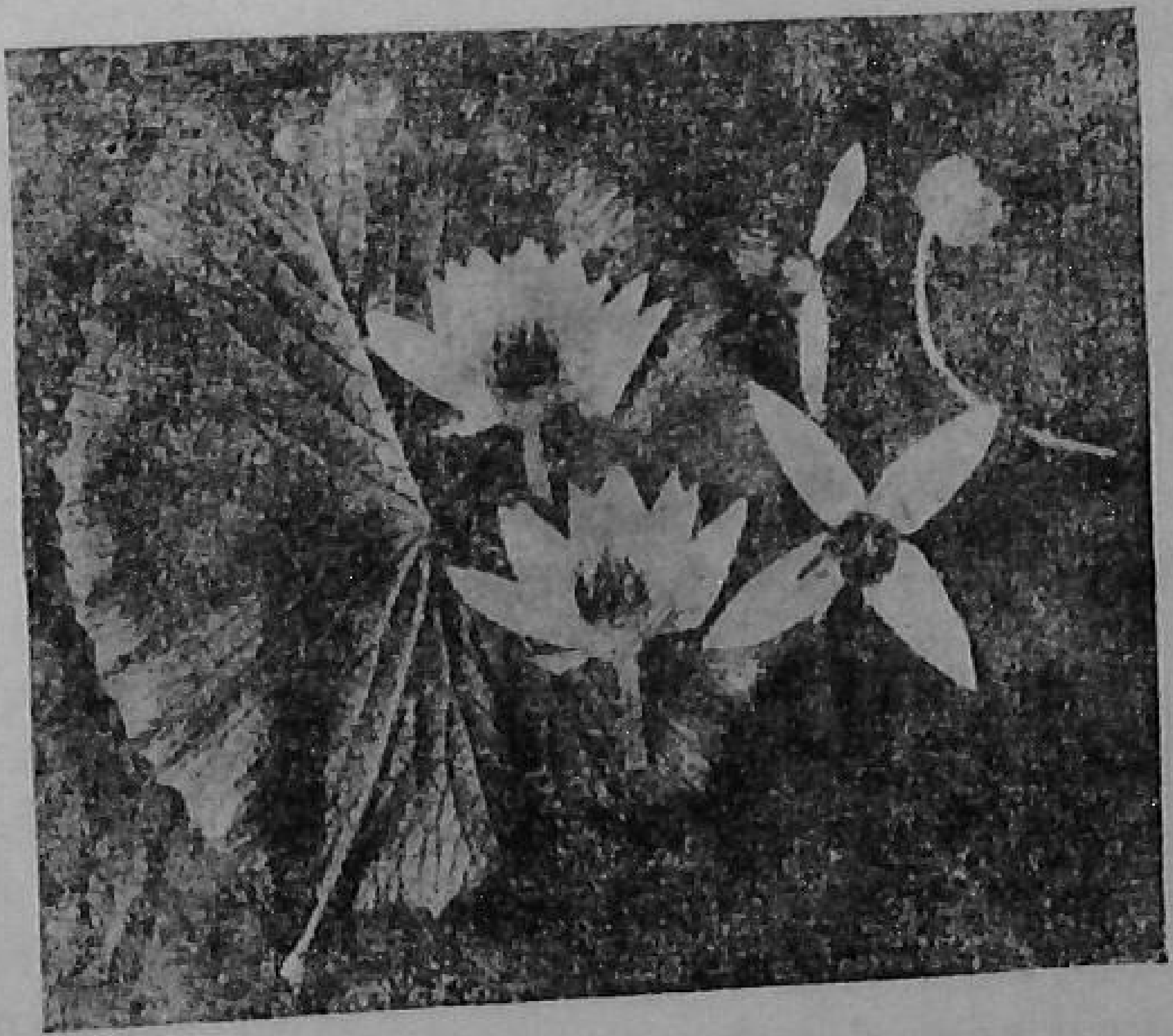

Fig. 354.—*Nymphaea pubescens*, Willd. Leaf and floral parts.

DISTRIBUTION—Tropics and N. Temperate zone.

Types :—*Nymphaea pubescens*, Willd.
Nelumbium speciosum L.

Nymphaea pubescens found usually in shallow stagnant water, creeping underground with long-stalked, large leaves, floating on the surface of water. *Leaves* rotund, with a deep sinus at the base, peltate. The lower surface of the leaf reddish with very

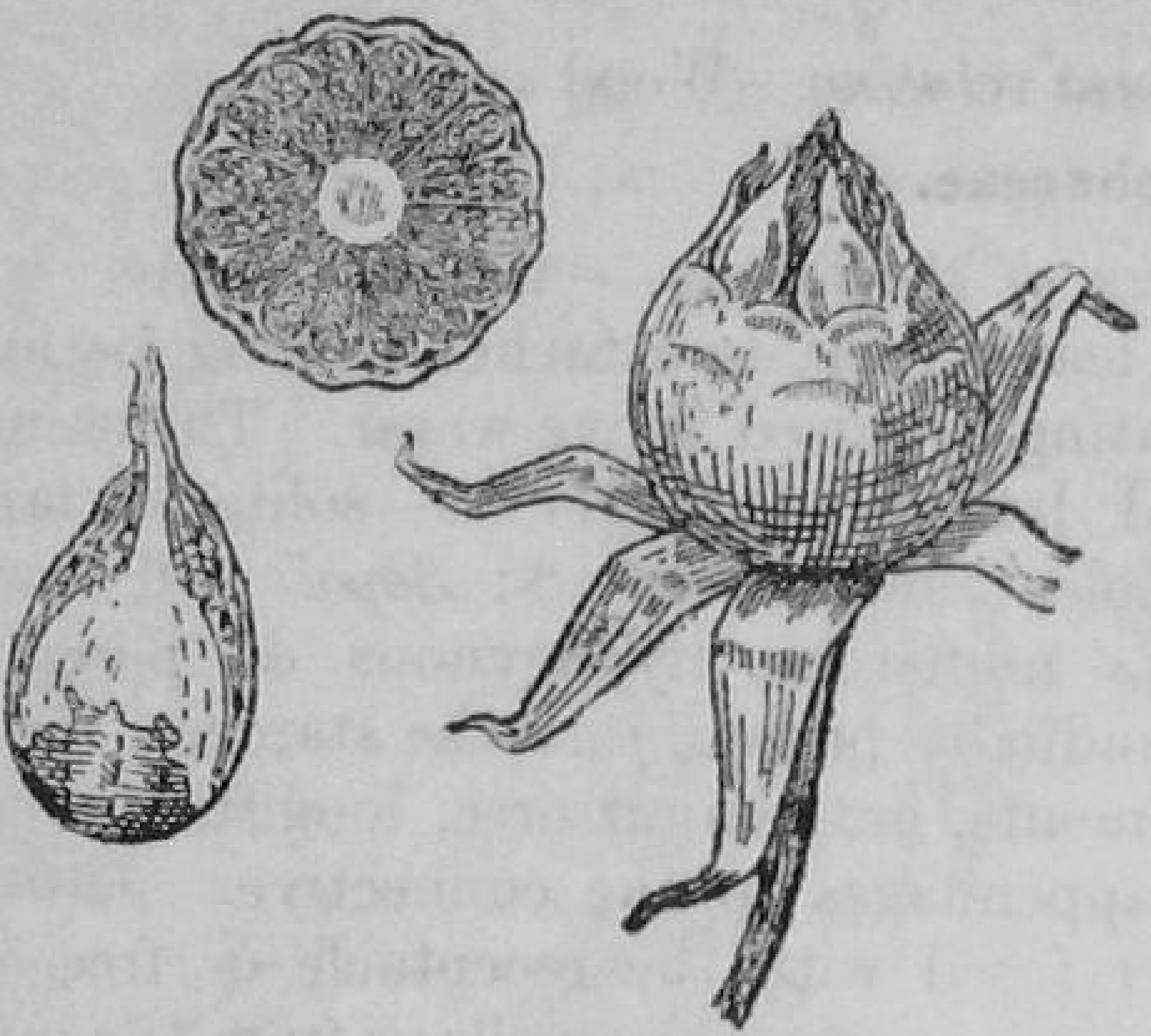

Fig. 355.—*Nymphaea pubescens*, Willd. Entire fruit, transverse section of the fruit and the seed.

prominent spongy veins and the upper surface shiny green, smooth and wax coated and therefore not wetted. *Flowers* solitary on long scapes and floating. *Sepals* 4, oblong. *Petals* are 12 or more, unequal, oblong, white or red. *Stamens* many with flat filaments. Both the petals and the stamens spirally attached to the outer surface of the ovary. *Ovary* of many carpels, fused with the fleshy receptacle. The *fruit* a soft berry with many cavities lined with seeds ; *Seeds* globular, tubercled, and enclosed by a sac-like aril ; contain both endosperm and perisperm.

Nelumbium speciosum is the well-known Lotus plant, flourishing in ponds and tanks. It has a stout rhizome which is laticiferous. Leaves long-stalked raised above the level of the water and cup-shaped in the middle. *Flowers* large, showy, solitary, and on long peduncles. *Sepals* 4 or 5, *Petals* 15 to 20 or more, unequal, white or red, deciduous. *Stamens* numerous, hypogynous, with a club-shaped appendage to the top of the connective. *Carpels* free, 10 to 20, separately sunk in the top-shaped receptacle. *Fruit* consists of the top-shaped receptacle with the ripe carpels imbedded.

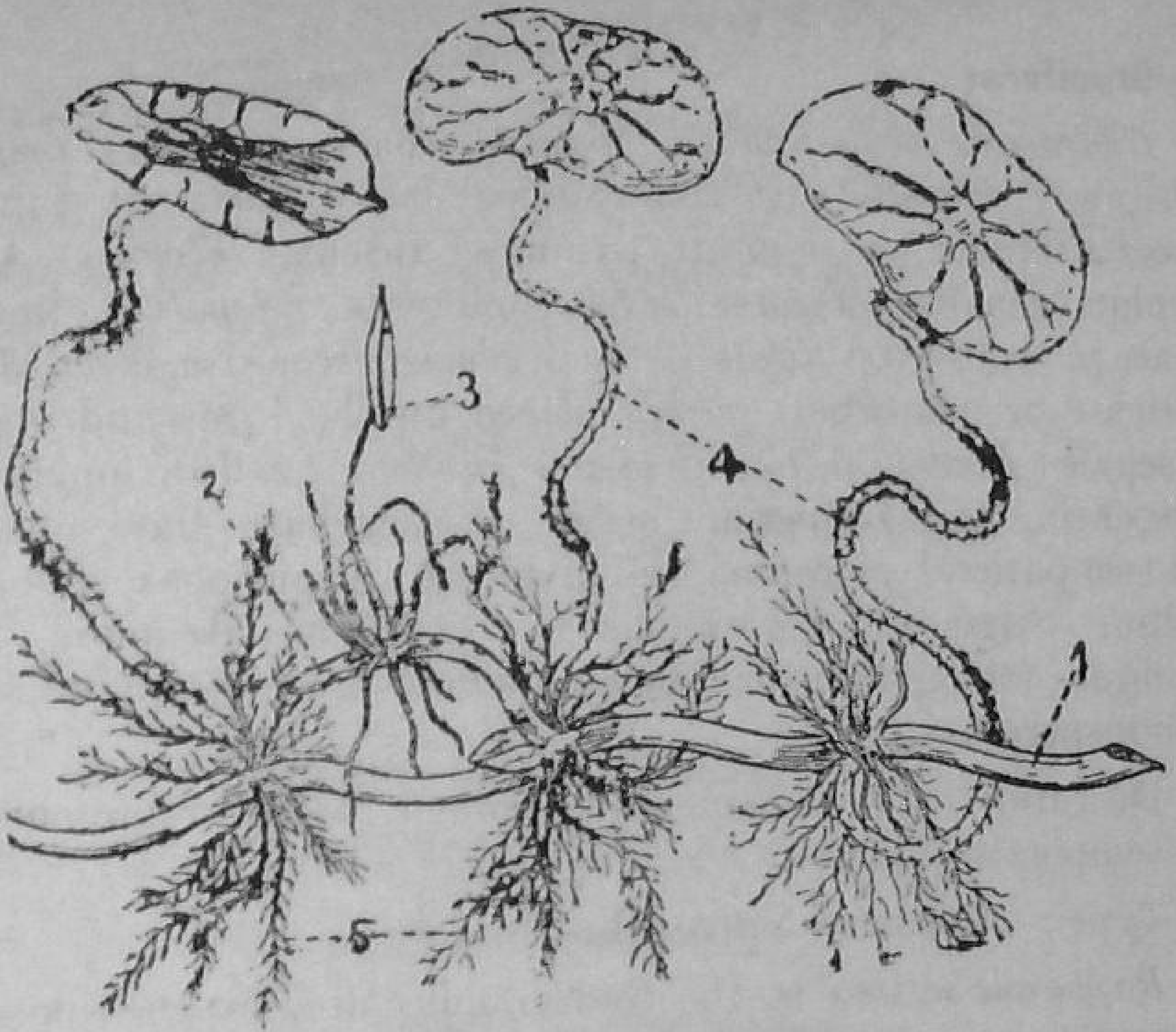

Fig. 356.—A plant of *Nelumbium speciosum*, Willd. 1. Rhizome; 2. young bud; 3. involute young leaf; 4. petiole; 5. roots.

Useful Plants.

Ornamental.—(1) Several *Nymphaea* spp suitable for water gardens. (2) *Victoria regia*, Victoria water Lily. (3) *Nelumbium speciosum*, *Lotus*—Rhizome of Lotus plant is commonly fried and eaten in South India particularly in Malabar.

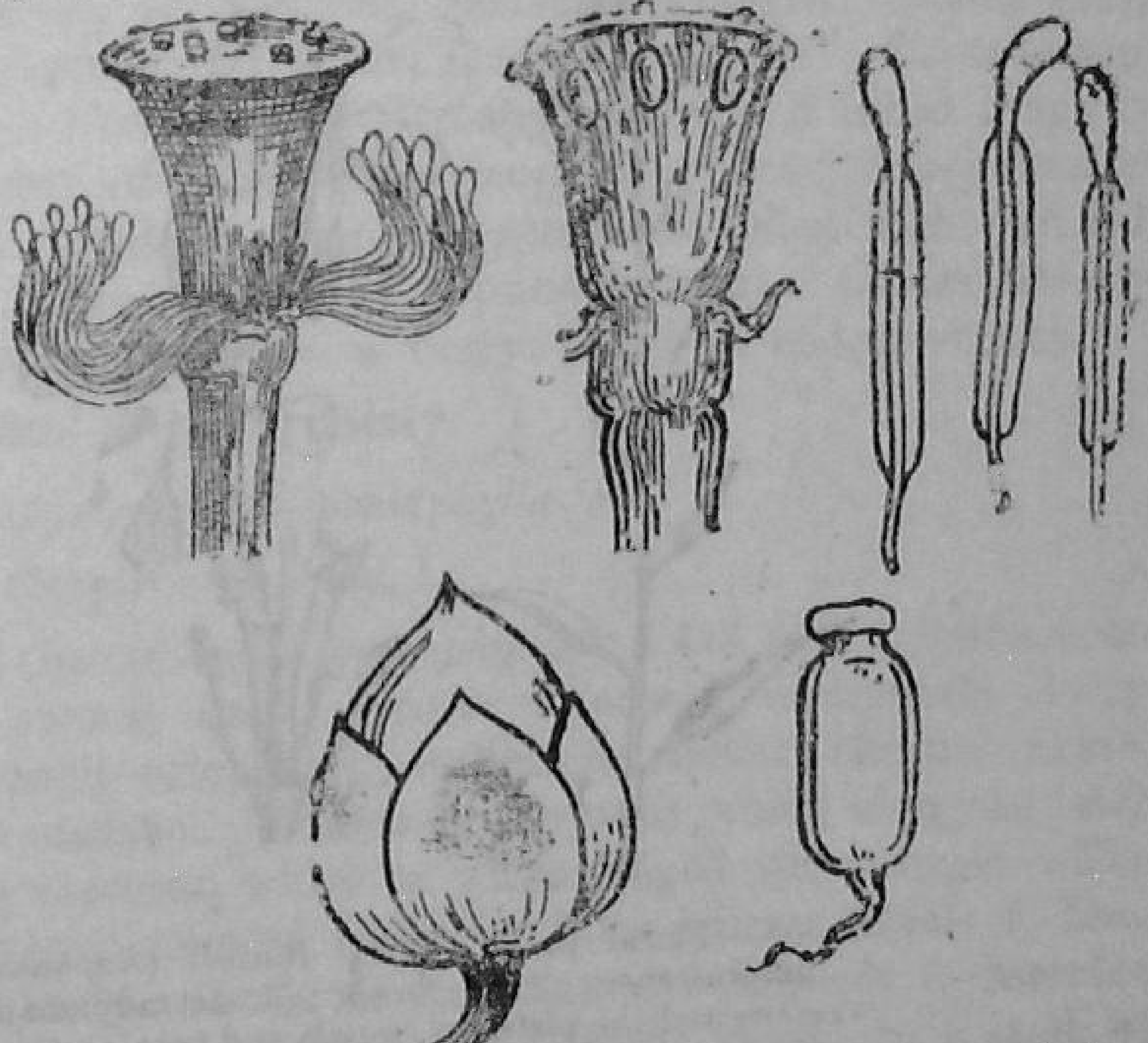

Fig. 357.—A flower bud, stamens, ovary and receptacle of *Nelumbium. Speciosum.*

3. Cruciferae.

Characters of the family.—Plants herbaceous, annual or perennial, rarely shrubby with watery juice; hairy, hairs not glandular. *Leaves* alternate or opposite, stipules absent. *Flowers* Actinomorphic, usually racemose, rarely bracteate. *Sepals* 4, free, imbricate in two series; *Petals* 4, equal, placed crosswise, often clawed, imbricate or contorted; *glands* placed on the torus and opposite the sepals; *stamens* 6, *tetradynamous, anthers* 2 celled, longitudinal dehiscence. *Ovary* superior, sessile, bicarpellate but unilocular with two parietal placentas and divided by a spurious membranous septum. Stigmas 3 or 2 or connate. *Ovles* usually many. *Fruit* a siliqua (elongated) or silicule (short) and bi-valved. *Seed* ex-endospermous.

DISTRIBUTION—cosmopolitan, though better represented in the temperate climate.

Type :—*Raphanus sativus*, L.

Raphanus sativus is the Radish, cultivated for the sake of its tuberous roots. It is biennial, with sessile, pinnately lobed leaves which are arranged in the radical fashion. *Inflorescence* terminal, corymbose when young and racemose when in fruit. *Flowers* white or pinkish white and ebracteate. *Sepals* green; narrow, 4 in whorls of 2, the inner whorl bulging at the base on account of the

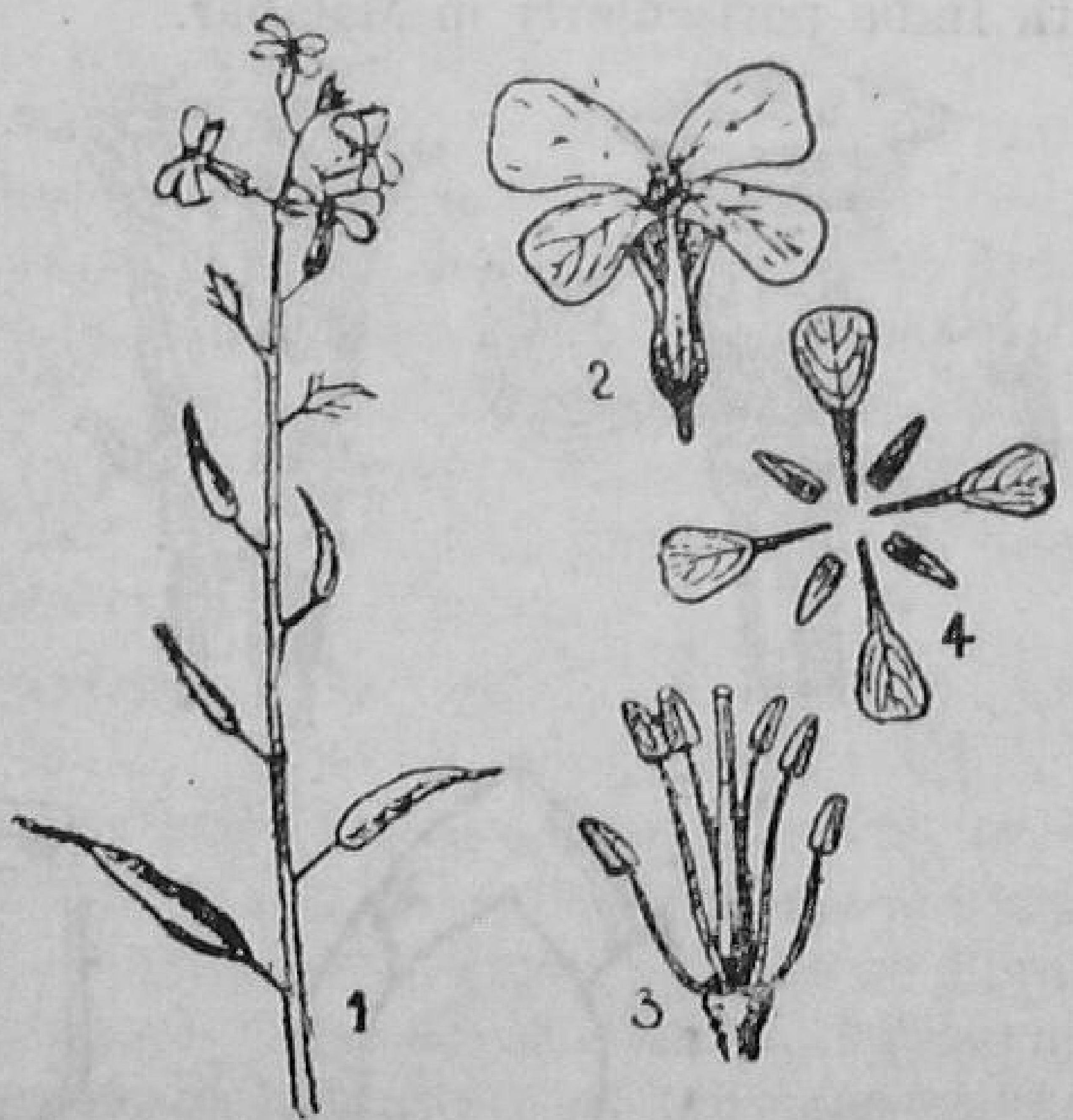

Fig. 358.—Floral parts of the Radish (*Raphanus*) 1. inflorescence; 2, a flower; 3. tetradynamous stamens and the pistil; 4. sepals and petals.

2 glands on the receptacle. *Petals* 4, free, clawed at the base and disposed cross-wise. *Stamens tetradynamous* with 2 glands close to the shorter stamens. *Ovary* superior, 2 carpelled with parietal placentation. *Fruit* a siliqua. *Seeds* brownish.

Useful plants.—

1. *Brassica juncea*-mustard. Spice and oil.
2. *Raphanus sativus*, L., Radish—root tuber.
3. *Brassica oleracea, var, capitata* L, cabbage.
4. *Brassica oleracea, var, botrytis*, -cauliflower.
5. *Brassica oleracea, var gemmifera*-Brussel sprouts.
6. *B. Caulorapa*-Kholrabi or knol-khol.
7. *Brassica Rapa, Linn*-Turnip-root.
8. *Nasturtium officinale.*—Water-cress.

Wallflower and Honesty—ornamental.

4. Capparideae.

Characters of the family. Herbs or shrubs, rarely trees, sometimes scandent. *Leaves* alternate or opposite, simple, digitately 3—7 foliolate, stipules minute or spiny. *Flowers* mostly actinomorphic, axillary or terminal, variously arranged. *Sepals* free, usually 4, valvate or imbricate ; *Petals* 4 to many. *Torus* elongated to short. *Stamens* few to many, anthers 2 celled longitudinally dehiscent, attached to the *gynophore* or knob. *Ovary* usually attached to a short or long *gynophore*, one-celled with parietal palcentas or more celled by spurious septa. *Ovules* few to many. *Fruit* a capsule or a berry. *Seed* ex-endospermous.

Distribution.—Tropics mainly.

Types :—*Gynandropsis pentaphylla.*
Capparis sepiaria, L.

The weed *Gynandropsis pentaphylla* is a tall, hairy, herbaceous annual with strong smell. *Leaves* alternate, exstipulate, long-petioled, palmately-compound ; leaflets 5, obovate-elliptic, acute, hairy on both surface. *Flowers* in corymbs which elongate later into bracteate racemes, white or white tinged with purple. The whole inflorescence covered with glandular hairs. *Sepals* 4, free, and in two whorls. *Petals* 4, long-clawed. *Stamens* 6, inserted about the middle on the gynophore. *Ovary* raised on a stalk or

gynophore, one-celled, with many ovules on two parietal placentae. *Fruit* a capsule, linear and opening by two valves. *Seed* reniform with a curved embryo.

Capparis sepiaria is a straggling shrub, with wiry branches forming bushes in hedges and scrubby places. *Leaves* oblong or oblong-lanceolate, with stipular thorns. *Flowers* small in umbels, *Sepals* 4 in two whorls. *Petals* 4, white. *Stamens* indefinite. inserted on the torus at the base of the gynophore, and not on the gynophore. *Ovary* on the gynophore with many ovules on parietal placentae. *Fruits* berried, black. *Seed* with bent embryo and kidney-shaped.

Over fifteen species of *Capparis* are found in South India and some of them have large handsome flowers.

Several species of this family occur in South India and they are mostly of the genera, *Cleome* and *Cadaba.*

Cleome has indefinite stamens but there is no gynophore. *Cleome chelidonii*, L. f., with its pink flowers occurs as a weed in clay and black cotton soil, *C. viscosa*, L., grows as a weed all over the plains. It has yellow flowers and the plant is viscously hairy.

The genus *Cadaba* has only 4 stamens on the gynophore, and the striking feature is the presence of a tubular disk, projecting from the centre of the flower. Seeds are enveloped in red arils.

Crataeva religiosa, Forst, is a small tree with broad corymbs of white flowers having stamens, with purple filaments when the tree is bare of leaves.

Useful plants.—

Capers (flower buds of *Capparis spinosa*, L) is of economic use.

5. Malvaceae.

Characters of the family.—Herbs, shrubs and trees, often with *stellate* hairs and *fibrous* stems. *Leaves* alternate, simple, stipulate, entire or lobed, palmate veined. *Flowers* bisexual, actinomorphic, axillary, solitary, sometimes clustered or paniculate; *Sepals* 5, valvate, united into a lobed or truncate calyx. Sometimes there is an involucre of bracts (*epicalyx*); *Petals* 5, free, *twisted*, adnate to the base of the staminal tube; *Stamens* numerous, *monadelphous* and anthers *one celled*; *Ovary* 3—5 or many often 5 celled with numerous ovules on axile placenta. *Style* branched or not. *Fruit* Capsular, or schizocarp breaking into cocci or rarely woody and indehiscent.

Distribution—All over the world except very cold regions.
Types :—*Pavonia procumbens*, Boiss.
Hibiscus Rosa-sinensis, L.
Gossypium Spp.—Cotton.

Pavonia procumbens is a small shrub growing in clayey soil. *Leaves* simple alternate, stipulate, broadly ovate, irregularly dentate, and long-petioled. *Flowers* solitary, axillary, with five triangular bracteoles, united at the base (epicalyx) *Calyx* of 5 triangular lobes. *Petals* 5, yellow, connate at the base and adherent to the staminal tube. *Stamens* united into a tube, and anthers of several groups at intervals. *Ovary* 5 celled with one ovule in each. *Fruit* a schizocarp, breaking into five, muricate, glabrous cocci.

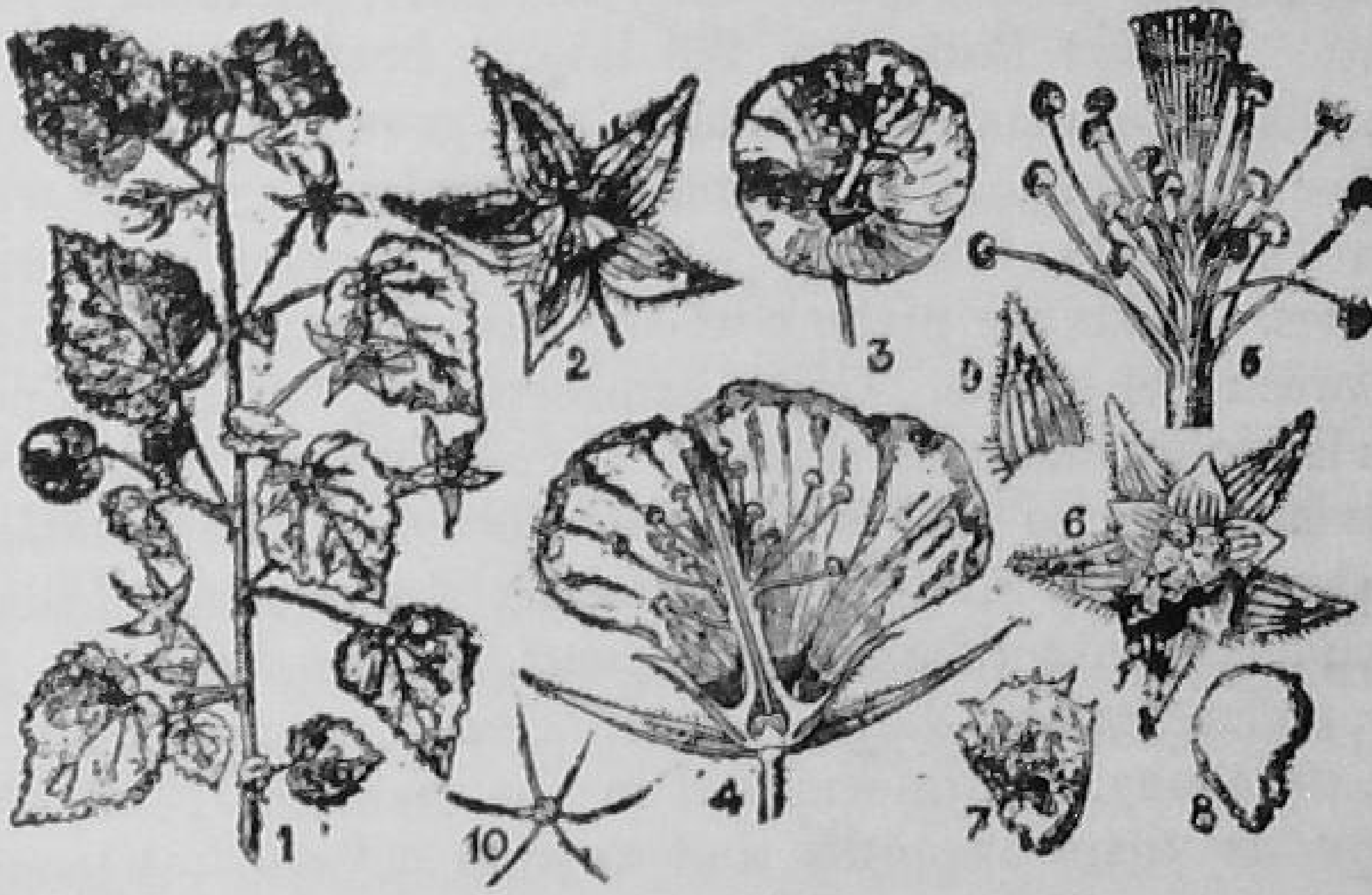

Fig. 359. *Pavonia procumbens*. 1. a branch ; 2. flower bud ; 3. flower 4. longitudinal section of a flower ; 5. staminal column and style branches 6. calyx and epicalyx ; 7. coccus ; 8. seed.

Hibiscus rosa-sinensis, L., is the common garden shoe-flower plant. A freely branching shrub producing large showy axillary solitary flowers. *Leaves* simple, stipules linear, short-stalked, ovate, dentate ; *Flowers* large with a jointed peduncle and with six or more linear green bracteoles (Epicalyx), *Calyx* with 5 triangular lobes. *Petals* 5 free, large, red, contorted, adnate at the base to the staminal tube. *Stamens* many united into a tube, antheriferous only at the upper half : *anthers* one-celled. *Ovary* superior 5 celled with many ovules on axile *placenta*; *style* long and branched into five at the free end.

Gossypium—**Cotton.**—The cotton of the world is obtained from more than one cultivated species of Gossypium (*Malvaceae*). They are broadly classified into two groups, namely, the Asiatic and the American. The former have 13 chromosome pairs that is

half the number of chromosomes that the American cotton plants have. Due to the difference in chromosome number, the American plants are bigger in their plant parts also, such as the leaf boll, lint length, etc., correspondingly. The Cambodia, the Bourbon and the Sea Island are examples of American cotton, while the Uppam or Ukkan or the Herbaceum and the Karunganni represent the Asiatic cottons. The botanical description varies for each cotton, but the following general description holds good for all cottons:

The plant is a shrub, an annual under cultivation. *Root System* deep, normal, tap root with laterals. *Stem* hairy, much branched. *Leaves* simple, alternate, stipulate, stipules linear, ovate-cordate, 3 to 5 lobed, hairy, dentate, undulate, palmate reticulate. *Flowers* Borne on the lateral branches, axillary and extra axillary, terminal and solitary, and growth of stem sympodial after flowering, Hermaphrodite, complete, regular with an involucre of bracts, bract size and shape varying according to the species. Glands are present at the base of each and sometimes also between the bracts. *Calyx* gamosepalous, cupular, 5 pointed or rounded lobes and resin dotted. *Corolla* yellow, red or white, 5 petals adhesive to each other, red spotted in the Asiatics and not red spotted in the Americans. *Androecium* Indefinite, monadelphous, antheriferous throughout, anther reniform, single lobed; pollen grains large. *Pistil* Ovary superior, 3 to 5 locular, style long, filiform enclosed in the staminal tube, stigmas as many as there are cells and twisted. *Fruit.*—A loculicidal capsule, 3 to 5 celled, popularly known as the "Boll" and the individual cells as "Locks." *Seeds* rounded or elongated, hairy, the hairs which are long and are of epidermal origin make up the "lint," valued as fibre and the short subepidermal outgrowths form the fuzz which is left on the seed after ginning. Seeds are used as an excellent cattle food. The cotton seed oil is put to a number of uses particularly in America such as soap making, oilcloth, artificial leather, as a salad, etc.

Physiology.—Cottons thrive in the tropical and warm temperate zones of both hemispheres. An abundance of sunshine and warm uniform temperature during the growing period is very desirable. Though deep rooted and apparently xerophytic it is very sensitive in its water relations. Too much of water is injurious especially in black soils. The plant relishes rains coming in after it is 6–7 weeks old and rains late in the season at the time of flowering is very harmful. Cottons thrive in black, red and loamy soils.

IMPORTANT CULTIVATED SPECIES AND VARIETIES

AMERICAN	ASIATIC
1. *Gossypium hirsutum, L.* (Cambodia)	1. *Gossypium arboreum*, L., Var. *neglectum forma indica* The Karunganni
2. *G. purpurascens*, Poir. (Bourbon)	2. *G. arboreum*, Var. *typicum* (The Nadam)
3. *Gossypium Barbadense*, Linn (Sea Island)	3. *G. herbaceum*, L., Var. *frutescens* (Uppam)

Useful Plants.—

(1) *Gossypium spp.*—Cotton—Textile importance.
(2) *Hibiscus esculentus*—Lady's finger—Vegetable.
(3) *H. Cannabinus*—Vegetable and fibre.
(4) *H. Sabdariffa*—Rosella—Vegetable and fibre.
(5) *H. Tiliaceus*—Fibre and green manure.
(6) *Thespesia populnea*—Wind break—Avenue—green manure.
(7) *Althaea rosea*—Hollyhock—ornamental.

6. Sterculiceae.

Characters of the family :—Trees or shrubs, rarely herbs. Hairs stellate. *Leaves* alternate or rarely sub-opposite, simple or digitately compound, stipulate. *Flowers* variously arranged, but inflorescence rarely terminal. Axillary, solitary or clustered, actinomorphic. *Sepals* 3—5 united, valvate; *Petals* 5 or absent, hypogynous free or adhesive to the staminal tube, contorted; *stamens* united into a tube with as many staminodes; sometimes in more than one series, or sometimes free. *anthers* 2 celled. *Ovary* of 2—5 or rarely 10—12 more or less united carpels or reduced to 1 carpel. *Ovules* 2 or more in each cell. *Style* simple or divided into lobes. *Fruit* dry, variously dehiscent or indehiscent. *Seed* with or without endosperm.

Distribution—Mainly Tropics and sub-tropics.

Types :—As types *Melochia corchorifolia*, L., and *Waltheria indica*, L., may be examined. *Helictres Isora*, L., is a common shrub of low jungles with large irregular crimson flowers. The petals are irregular, stamens tubular and the ovary is stalked. The fruit consists of five linear follicles, more or less spirally twisted, and gives a strong but coarse fibre.

Several species of *Pterospermum* occur in the forests of low hills. Fruits of this genus are woody with winged seeds.

Guazuma tomentosa, Kunth., is grown as an avenue tree. Petals of this plant are concave with two strap-shaped appendages at the apex of each petal. Staminodes alternate with stamens.

Useful Plants.—

(1) *Theobroma cacao*, Cocoa and chocolate.

(2) *Cola vera*—Cola or Kola nuts.

7. Tiliaceae.

Characters of the family:—Trees or shrubs, rarely herbs; *Leaves.* alternate, rarely opposite, simple, stipules deciduous. *Flowers* Cymose, actinomorphic, and *Sepals* mostly 5 and valvate; *petals* free, present or absent; sometimes like the sepals, contorted, imbricate or valvate. *Stamens* numerous, free or *shortly connate* at the base or in 5—10 bundles; *anthers* 2 celled, longitudinal dehiscence, or by apical pore; *ovary* superior, sessile, 2—10 celled; *style* simple; *ovules* many, placentation axile; *Fruit* 2—10 celled. Capsular or drupaceous.

Distribution—Throughout the world.

Types :—*Corchorus olitorius*, Linn.
C. trilocularis, Linn.

Corchorus olitorius, Linn. though not truly indigenous to South India, is found growing very common and wild that it can be studied as a type. The plant is an erect, branched (in South India) glabrous annual met with in cultivated soils (fallow rice-fields). *Leaves* are stipulate $2\frac{1}{2}$ to 4 inches by $1\frac{1}{2}$ to 2 inches, elliptic lanceolate, acute or acuminate, glabrous and serrate. The teeth at the base are produced into threadlike appendages—auricles. *Flowers* are 1-3, yellow, leaf opposed. *Sepals* are 3-5, valvate. *Petals* are 3-5 valvate. *Stamens* numerous, arranged on the raised torus. *Ovary* superior, 2 to 10 celled. *Style* short. *Fruit* a loculicidal beaked capsule of 5 valves aud 10 ribs. **Useful Plants.**—The important fibre, Bengal Jute, is obtained from the stem of this plant and another species *Corchorus capsularis*, Linn. *Berrya Ammonila*, Roxb—is Trincomalle wood for timber.

8. Rutaceae.

Characters of the family.—Shrubs or trees, rarely herbs. *Leaves* simple or compound, *mostly gland dotted*, oil fragrant; exstipulate. *Flowers* in axillary, or terminal cymes or panicles;

rarely zygomorphic; *Sepals* 4-5 imbricate, free or united, *Petals* 5, free, imbricate; *stamens* the same or double the number of the

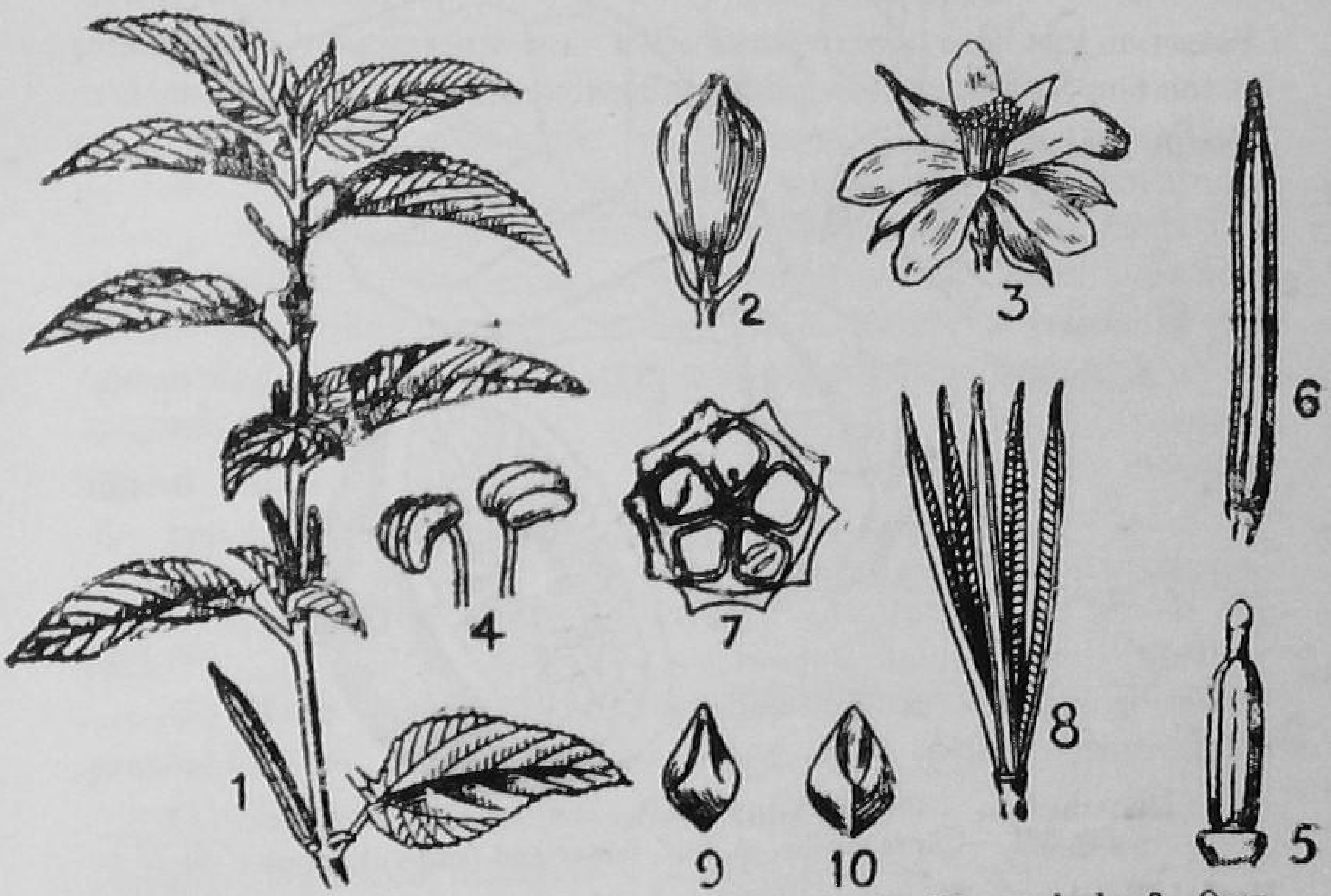

Fig. 360.—*Corchorus olitorius*, Linn 1, A branch; 2, Flower bud; 3, Open flower; 4, anthers; 5, pistil, 6, Fruit; 7, T. S. of fruit; 8, Dehisced fruit; 9 and 10 seeds.

petals, rarely many, free; *Anthers* celled, introrse, longitudinal dehiscence, connective often glandular at the apex; disk usually present with the stamens, annular or lobed. *Ovary* superior syncarpous and often 4—5 celled. *Styles* free or united. *Fruit* berry or *hesperidium*. *Seeds* endospermous or not.

Distribution.—Temperate and warmer regions. Abundant in S. Africa, Australia and India.

Type :—*Citrus nobilis*, L. The King Orange.

The Orange Tree, *Citrus nobilis*, has spiny branches with alternate, one-foliate leaves that are provided with winged petioles. The *leaflet* elliptic or oblong-elliptic, studded with pellucid oil glands, entire or crenate. *Flowers* axillary, solitary, or in cymes. *Calyx* cup-shaped, five-toothed. *Petals* usually five, linear oblong, thick, imbricate. *Stamens* many, inserted round an annular disk. *Ovary* many-celled with a cylindric single style and capitate stigma. *Fruit* a many-celled berry with a few seeds immersed in fleshy hairs growing from the pericarp and filling the cavity. *Seed* with coriaceous testa and several embryos (*polyembryonic*).

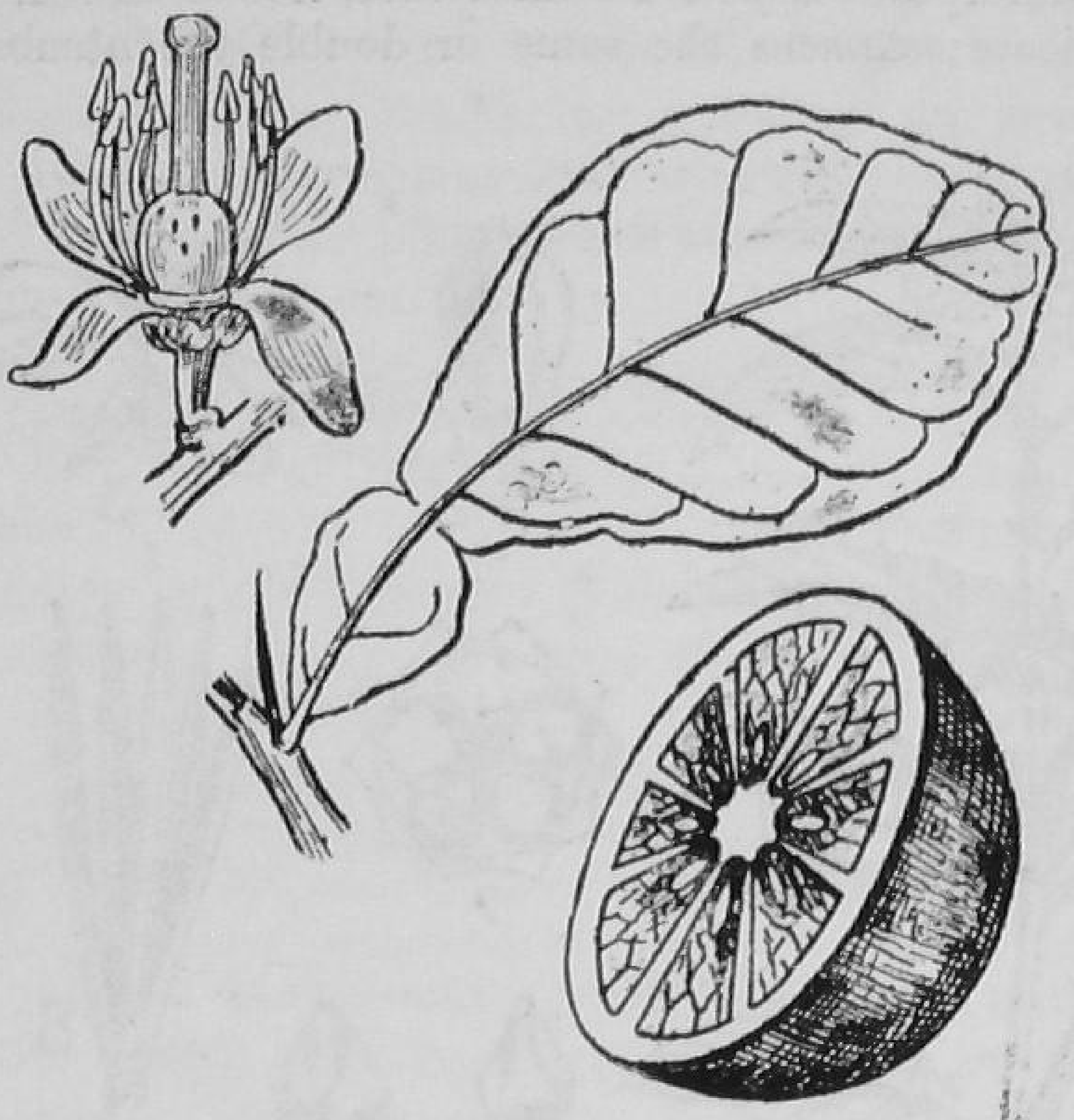

Fig. 361.—*Citrus nobilis.* A leaf, flower and fruit cut across.

Useful Plants.—

(1) *Citrus sinensis*—'Sathgudi' or chinee.

(2) *C. Nobilis*—The King Orange.

(3) *C. Aurantifolia*—Lime.

(4) *Aegle marmelos*—Bael fruit.

(5) *Feronia elephantum*—Wood apple.

(6) *Murraya Koneigii* sp—Curry leaf.

(7) *Chloroxylon swietenia*—Satin wood for furniture.

9. Meliaceae.—

Characters of the family.—Trees or shrubs, with hard scented wood. *Leaves* alternate *mostly pinnate compound;* stipules absent; *Flowers* bi-sexual, actinomorphic and in panicles. *Calyx*-small, 4 to 5 lobed, imbricate; *Petals* 4 to 5 free or partially united; contorted or imbricate, or adhesive to the staminal tube and valvate; stamens 8 to 10 rarely numerous, mostly with connate filaments and the anthers often sessile in the tube and introrse; Disk various. *Ovary* Superior 3—5 celled; *Stigma* disciform or capitate; *Ovules* mostly single. *Fruit* a berry or a capsule, rarely a drupe; *seed* with or without endosperm, winged or not.

Distribution.—Warm regions of the world.

Type :—*Azadirachta indica*, A. Juss. (The Neem or Margosa Tree).

This is a common tree with stout trunk. *Leaves* alternate, exstipulate, imparipinnate; leaflets obliquely lanceolate or falcate, toothed, sub-opposite, nine to thirteen. *Flowers* in axillary panicles. *Calyx* 5 toothed. *Petals* 5 white, narrowly obovate or oblong or spathulate. *Stamens* form a tube, shorter than the petals, cylindric, widening above, lobed at the apex ; *anthers* within the tube, opposite to the lobes. *Ovary* 3 celled. *Fruit* one-seeded drupe. *Seeds* large, non-endospermic and with thick cotyledons.

Useful Plants.—

(1) *Lansium domesticum*, Langsat—Fruit edible.

(2) *Azadirachta indica*, the Neem or Margosa tree—Timber and oil.

(3) *Melia Azedarach*, Persian Lilac—cultivated for its ornamental flowers.

(4) *Swietenia Mahogani*—Mahogany wood.

(5) *Chuckrasia tabularis* A. J.—Chittagong wood.

(6) *Cedrela Toona* T—The Toon tree, wood valuable.

(7) *Soymida febrifuga*—Indian Red wood.

(8) *Chloroxylon Swietenia*—Satin wood.

(9) *Dysoxylum malabaricum*—White Cedar.

10. Rhamnaceae.—

Low trees or shrubs, rarely herbs, sometimes scandent. *Leaves* simple, alternate or opposite, stipulate and stipules sometimes thorny. *Flowers* mostly cymose, small rarely polygamous—dioecious *Calyx* 4 to 5 lobed, valvate, *Petals* 4–5 small or absent, free; *stamens* 4–5 *opposite to and often embraced by the petals ;* anthers-2 celled longitudinal dehiscence; *Disk prominent* perigynous, sometimes lining the calyx tube; *ovary* sessile, free or sunk in the disk; 2—4 celled; style shortly lobed; *ovules* solitary. *Fruit* drupaceous or winged. *Seeds* endospermous.

Distribution.—Mostly Tropics, also in Temperate regions.

Type :—*Zizyphus Jujuba*, Lamk.

This is a much branched low tree with stipular thorns. *Leaves* alternate, simple stipules short-stalked, ovate-elliptic, unequal at the base, three-nerved, entire or finely dentate green

above, and densely hairy below. *Flowers* small in axillary cymes, greenish yellow. *Sepals* 5 valvate, woolly outside and keeled on the inner side. *Petals* 5, small, concave. *Stamens* 5 opposite the petals. *Ovary* immersed in a 10-lobed disk, 2-celled; *style* 2-branched. *Fruit* globose, drupaceous, two-seeded.

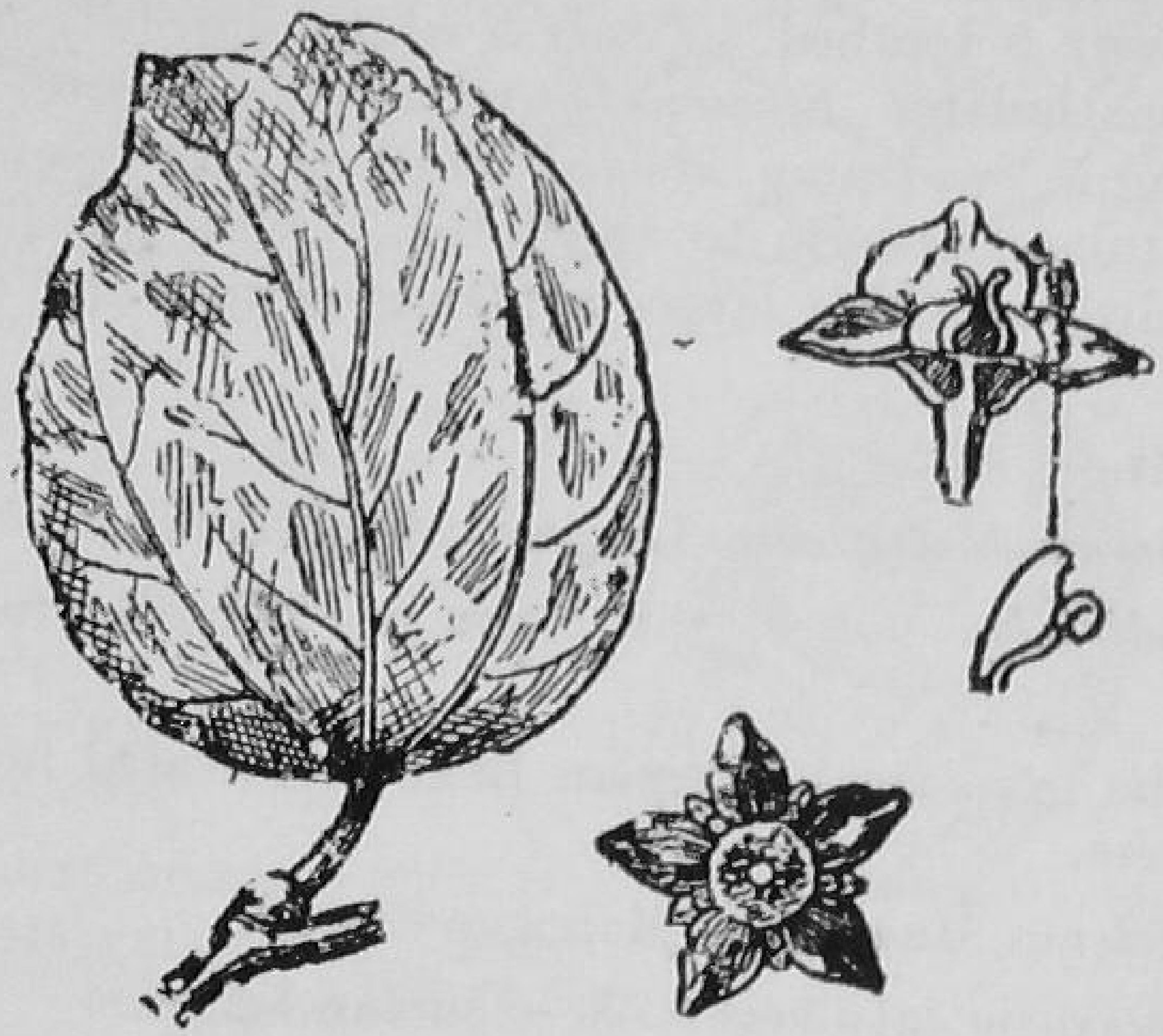

Fig. 362.—*Zizyphus Jujuba,* A leaf, a flower and a section of the flower.

Useful Plants.—

(1) *Zizyphus Jujuba*—The Jujube or Chinese Edible Fruit.

(2) *Rhamnus Purshiana*—Cascara Sagrada—Medicinal.

(3) *Ventilago maderaspatana*—Popli-Chekke-root bark.

11. Ampelidaceae (Vitaceae).

Characters of the family.—Mostly climbing shrubs with tendrils or small trees, with stem *nodose* or *jointed* and often with watery juice. *Leaves* alternate or the lower sometimes opposite, simple or variously compound, stipules petiolar or absent. *Flowers* bisexual or male and female; actinomorphic, small, in *leaf opposed* spikes, racemes, panicles or cymes; *calyx* small; 4–5 lobed; *Petals* 4–5 free or united, caducous, *valvate; stamens* 4–5, *opposite the petals* inserted at the base of the disk which is prominent; *anthers* 2–celled, longitudinal, *Ovary*–2–6 celled, cells 1–2 ovuled, style short; stigma capitate. *Fruit,* a berry very *watery; seed* endospermous.

Distribution.—Tropics and warm temperate regions.

Types :—*Vitis vinifera*, Linn. Grape Vine.

Cissus quadrangularis, Linn.

Vitis vinifera, Linn. is the grape vine. A tendril climber, first introduced into India about 1889 by a French priest, the Rev. Father Larmey. It is now cultivated on a large scale throughout India, Pattiveerampatti (Madura), Kodaikanal, Krishnagiri and Penukonda, Bangalore, being important centres for the south. The *leaves* are simple, large, variously lobed with tendrils opposite to the leaves. *Stipules* 2, deciduous. *Flowers* polygamo-diœcious in leaf opposed thyrsus. *Calyx* cupular, with 5 obscure teeth. *Petals* not showy, 5; coherent by their tips and deciduous as a calyptra. *Stamens* 5, filaments slender, long in male and shorter in bisexual flowers. *Anthers* introrse. *Disk* prominent of 5 hypogynous glands. *Ovary* 2-celled, 2 ovules in each cell. *Style* very short, stigma obtuse. *Fruit* a two-celled juicy berry. *Seeds* hard, 4 or less. The plant is propagated by cuttings or layering. Budding is also practised in some parts.

Cissus quadrangularis, Linn. is very common, wild in hedges where it rambles over long distance. The young stem and the leaves are used as leafy vegetable in Indian houses.

Useful Plants.—

(1) *Vitis Vinifera*, L—the Grape vine (the various cultivated forms belong to this species).

12. Sapindaceae.

Characters of the family.—Trees, shrubs or climbers; *Leaves* generally alternate, rarely opposite, simple or compound; generally exstipulate; *Flowers* actinomorphic or zygomorphic, often very much reduced and usually polygamous or dioecious, variously arranged. *Sepals* 4—5 lobed or of 4—5 sepals imbricate, *Petals* 3—5, equal or unequal, often absent. *Disk* prominent. *Stamens* —8 inserted within the disk, *anthers* 2-celled; *Ovary* superior, 1—4 often 3 celled. *Style*—2—4, simple or divided; *Ovules* 1—2 in each cell; *Fruit* various; *seeds* exendospermous, often *arillate.*

DISTRIBUTION.—Mainly tropical.

Type :—*Cardiospermum Halicacabum*, L. (The Balloon vine).

The plant is a tendril climber, with wiry stems and branches. *Leaves* alternate, exstipulate, long-stalked bipinnate; leaflets coarsely toothed. *Flowers* small in axillary umbellate cymes, irregular and polygamous. The flower-stalks slender, but the

peduncle is stiff and erect with two tendrils below the flowers. *Sepals* 4, concave, outer pair small and inner large. *Petals* 4 in

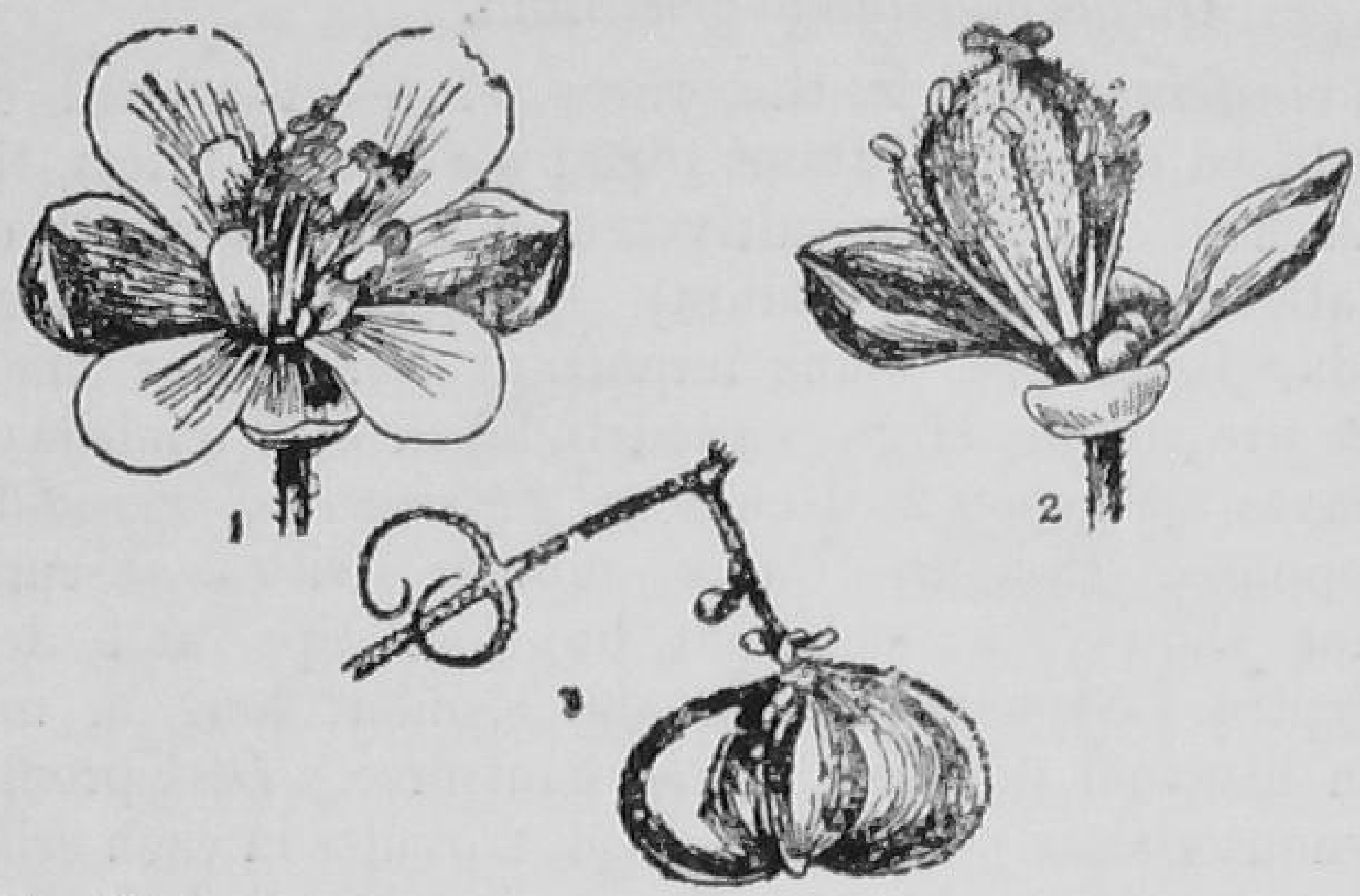

Fig. 363.—*Cardiospermum Halicacabum.* 1. a male flower 2. a bisexual flower ; 3. fruit.

two pairs, 2 near the stamens with basal scales and the remote from the stamens with a crested appendage. *Disk* unilateral of 2 distinct glands, opposite the small lower petals. *Stamens* 8, eccentric, with hairy, unequal filaments. *Ovary* 3 celled, with one ovule in each. *Fruit* a 3-valved inflated capsule. *Seeds* black, globular, with a white heart-shaped mark, the aril.

Useful Plants.—

(1) *Sapindus emarginatus*—Substitute for soap.

(2) *Nephelium Litchi*,—Litchi fruit tree introduced from China.

(3) *Dodonea Viscosa*—green manure.

(4) *Schleichera trijuga*, useful in many ways ; seed gives an oil, aril edible ; wood very hard used for rice pounders, for carts, etc. The best lac is produced on its twigs.

13. Anacardiaceae.

Characters of the family.—Trees or shrubs, often with *resin ; Leaves* alternate, rarely opposite, simple or *compound ;* exstipulate; *flowers* Bi-sexual, male or female mostly actinomorphic, small, in axillary or terminal paincles. *Calyx* 3—5 sepals ; sometimes spathaceous and accrescent ; *Petals* 3—5 free, rarely absent, imbricate or valvate ; *Disk* fairly prominent. *Stamens* 3—5 or double the number of petals ; *ovary.* superior, 1-celled, rarely 2—5 celled,

carpels rarely free. *Styles* 1—3 often widely separated. *Ovule* solitary. *Fruit* generally a drupe. *Seed,* with or without endosperm. *Cotyledons* fleshy.

Distribution.—Mainly tropics.

Types :—*Mangifera indica*, L. The Mango.
Odina Wodier, Roxb.

Mangifera indica is a tree 50 feet or more in height in wild condition. *Leaves* crowded at the ends of branches, alternate simple, petioled and exstipulate, oblong-lanceolate, entire,coriaceous. *Flowers* in dense terminal panicles, polygamous with jointed pedicels. *Bracts* deciduous. *Petals* 5 rarely 4 free, adnate to the disk, imbricate with a lobed glandular scale. *Disk* fleshy, 4 to 5 lobed. *Stamens* 5 inside or on the disk purple, 1 or 2 only fertile, the others slender and sterile, tipped with a small gland. *Ovary* 1 celled, oblique, sessile with a lateral style and a simple stigma. *Ovules* pendulous from a basal or a lateral funicle. *Fruit* a large fleshy resinous drupe with a fibrous compressed stone. *Seeds* large ovoid, oblong, compressed, with a thin testa; endosperm not found; cotyledons plano-convex, often unequal; radicle slightly curved upwards.

Odina Wodier is a deciduous evergreen tree with stout, soft branches. *Leaves* clustered at the ends of branches alternate, imparipinnate, leaflets three to four pairs, opposite, ovate-oblong, glabrous, shining, 3 to 6 in., long, exstipulate. *Flowers* monoecious or dioecious, shortly pedicelled in simple panicles. *Calyx* 4 lobed, persistent lobes rounded, imbricate. *Petals* 4 imbricate. *Disk* 8 lobed annular. *Stamens* 8, inserted below the disk; filaments in *male flowers* unequal, subulate with ovate or sagittate anthers. In *female flowers*, the anthers are very short, small and sterile. *Ovary* in male flowers abortive; in female flowers ovoid or sub-globose, one-celled rarely four celled. *Style* 4, distant from the four corners of the top of the ovary, erect; stigma small, peltate. *Ovule* pendulous from the top of the cell. *Fruit* a small, compressed, red obovoid, thinly fleshy drupe. Stone hard, one-celled, seed bearing. *Seed* compressed on a funicle; with a membranous testa and two cotyledons plano-convex curved with a superior thick radicle.

Useful Plants.—

(1) *Mangifera indica*—The Mango.
(2) *Anacardium occidentale*—Cashewnut.
(3) *Pistacia vera*—Pistachio nut.
(4) *Spondias Mangifera*—Hog plum.

Fig. 364.—Mango.

(5) *Semecarpus anacardium*—Marking nut.

(6) *Odina wodier*—excellent hedge, easily raised by stumps; also for green manure.

(7) *Buchanania Lanzan*—Kernels of the seeds edible.

(8) *B. angustifolia*—(‘*Sara paruppu*’)—Kernels of seeds edible.

14. Leguminosae.

Characters of the family—Trees, shrubs or herbs, sometimes climbing; *leaves* simple to bipinnate; *stipules* generally present; *Flowers* actinomorphic to zygomorphic; *Petals* free or some partially united; *Stamens* numerous to few, free or variously united, often *diadelphous; carpels* solitary, superior; *fruit* mostly a *legume*. Seeds with practically no endosperm.

Distribution.—Worldwide. This is 2nd largest family and is sub-divided into 3 sub-families namely—*Papilionaceae*, *Caesalpiniaceae* and *Mimosoideae*.

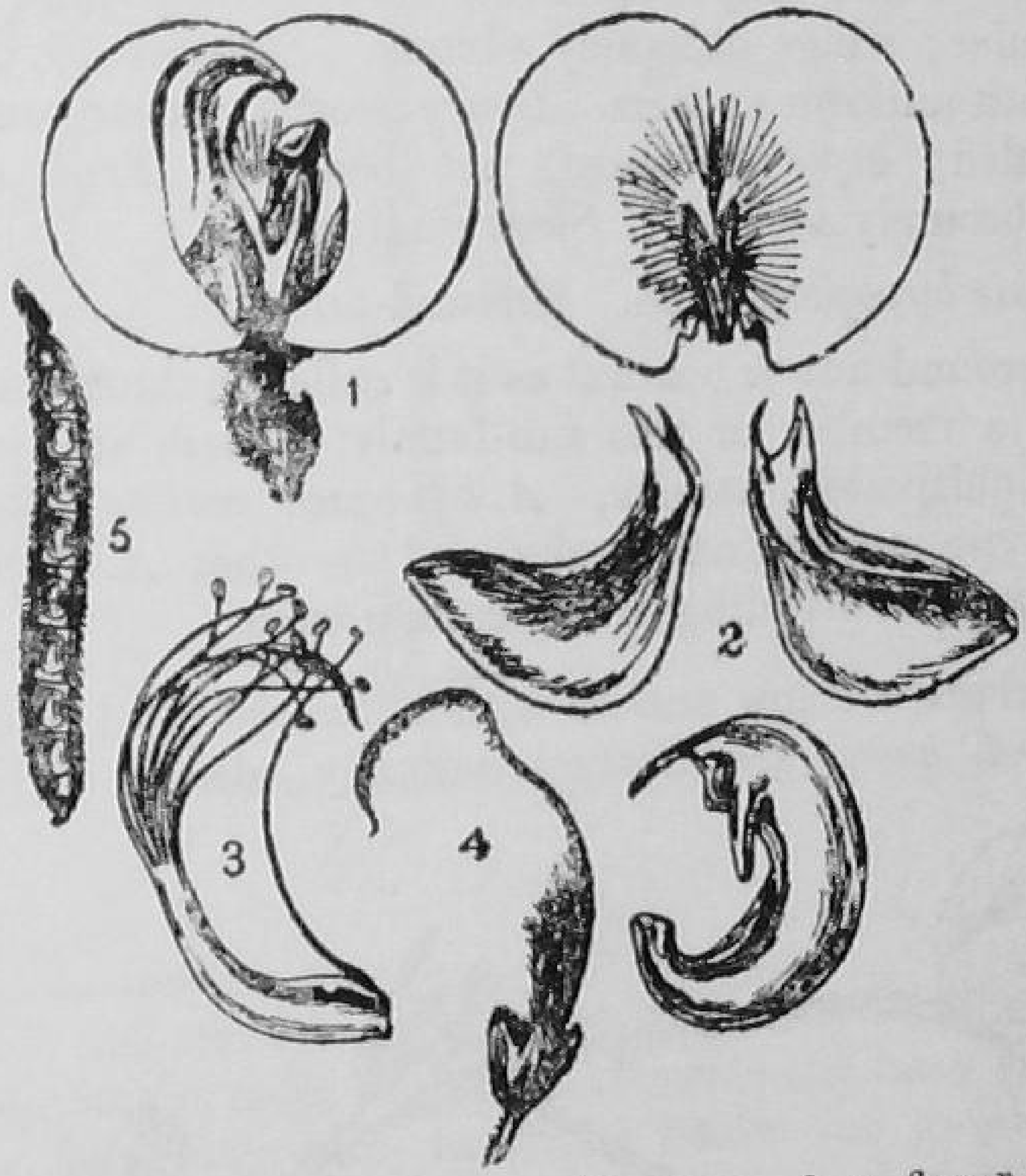

Fig. 365.—*Phaseolus* flower and its parts. 1. a flower; 2. petals; 3. stamens; 4. pistil; 5. a fruit.

Papilionaceae.—Mostly herbs and shrubs, some are trees, some climbers; *Leaves* simple or compound; *flowers zygomorphic* mostly bisexual; *sepals* usually 5, more or less united into a tube; *Petals* 5 imbricate, free, the upper (adaxial) exterior and forms the *standard*, the two lateral (*alae* or wings) more or less parallel with each other, the interior and lower two are united by their lower margins into a *Keel* (boat shape); *stamens* inserted with the petals, often 10, mona-delphous or dia-delphous, mostly all

perfect, anthers 2. lobed, longitudinally dehiscing ; *Fruit* a legume ; *Seeds* without or with-scanty endosperm.

Distribution.—World wide.

Type :—*Tephrosia purpurea*, Pers.—The *Kolingi*.

This is a common erect, freely branching, herbaceous weed, and very commonly cultivated as a green manure crop. *Leaves* alternate, compound, imparipinnate ; leaflets many, opposite, obovate-oblong, parallel-nerved, silky beneath ; stipules narrow-lanceolate. *Flowers* in terminal or leaf opposed racemes ; bracts not longer than the pedicels. *Calyx* bell-shaped 5 lobed-lobes acuminate. *Petals* papilionaceous, clawed, deep pink ; standard sub-orbicular ; wings obliquely oblong. *Stamens* 10, diadelphous (9+1), with uniform anthers. *Ovary* sessile, linear, one carpelled many-ovuled ; style flattened, not bearded. *Fruit* a flattened legume, obscurely septate. *Seeds* reniform.

Arachis hypogaea, Linn. (Ground-nut)

The ground-nut or pea-nut as it is called in America, is *Arachis hypogaea*, a member of this sub-family. There are two varieties which are cultivated, namely, *A. hypogaea variety fastigata*—The Burmah type, upright and bushy, and the other *A. hypogaea var. procumbens*, the spreading or the runner type.

The plant is a low annual with a tap root and laterals, fairly deep. *Root hairs* are characteristically absent. The *stem* is

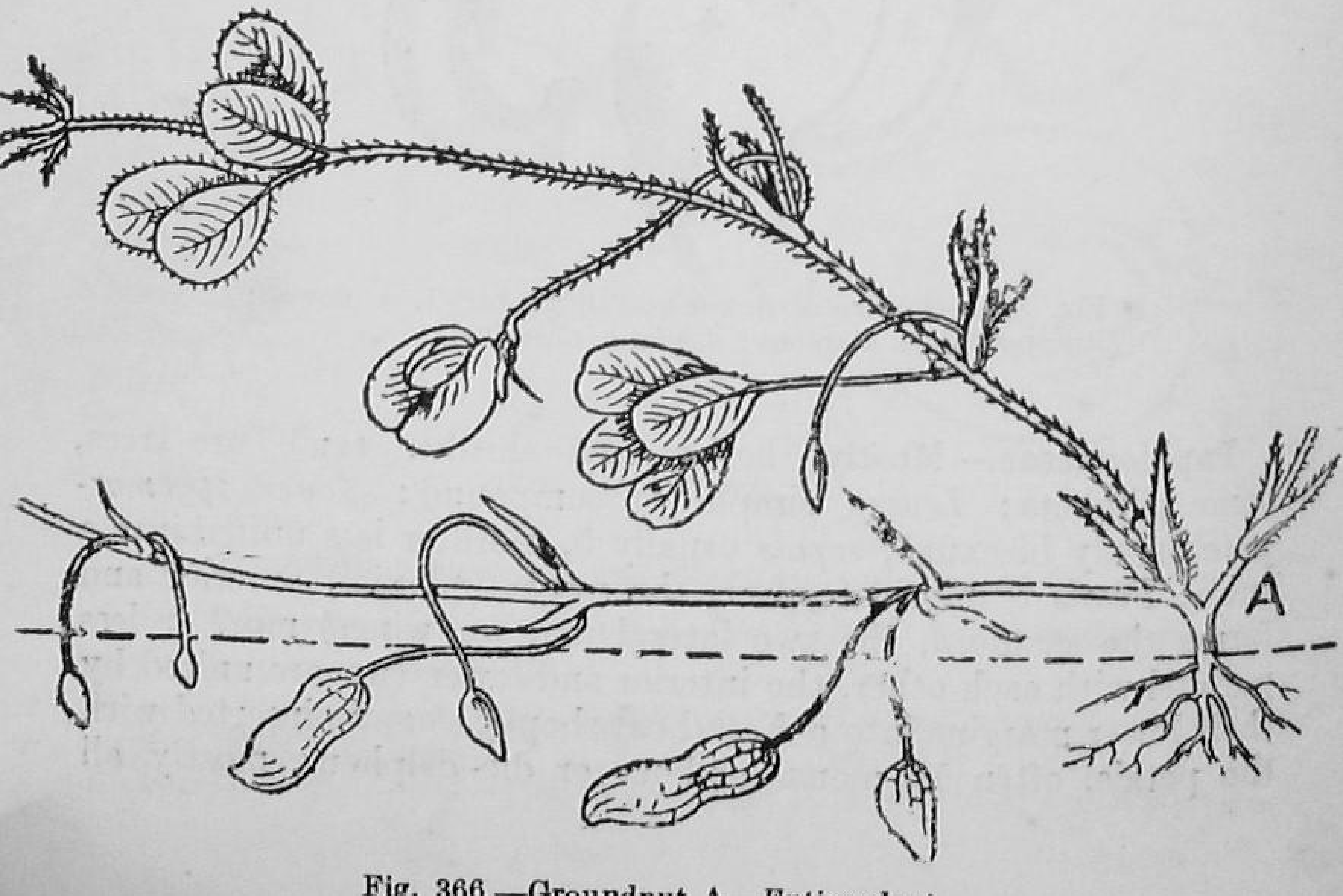

Fig. 366.—Groundnut A—*Entire plant.*

thick, angular, hairy and branching. *Leaves* alternate, pinnately compound with two pairs of sub-sessile entire leaflets, stipulate. stipules elongated and adhere to the petiole base. *Flowers*

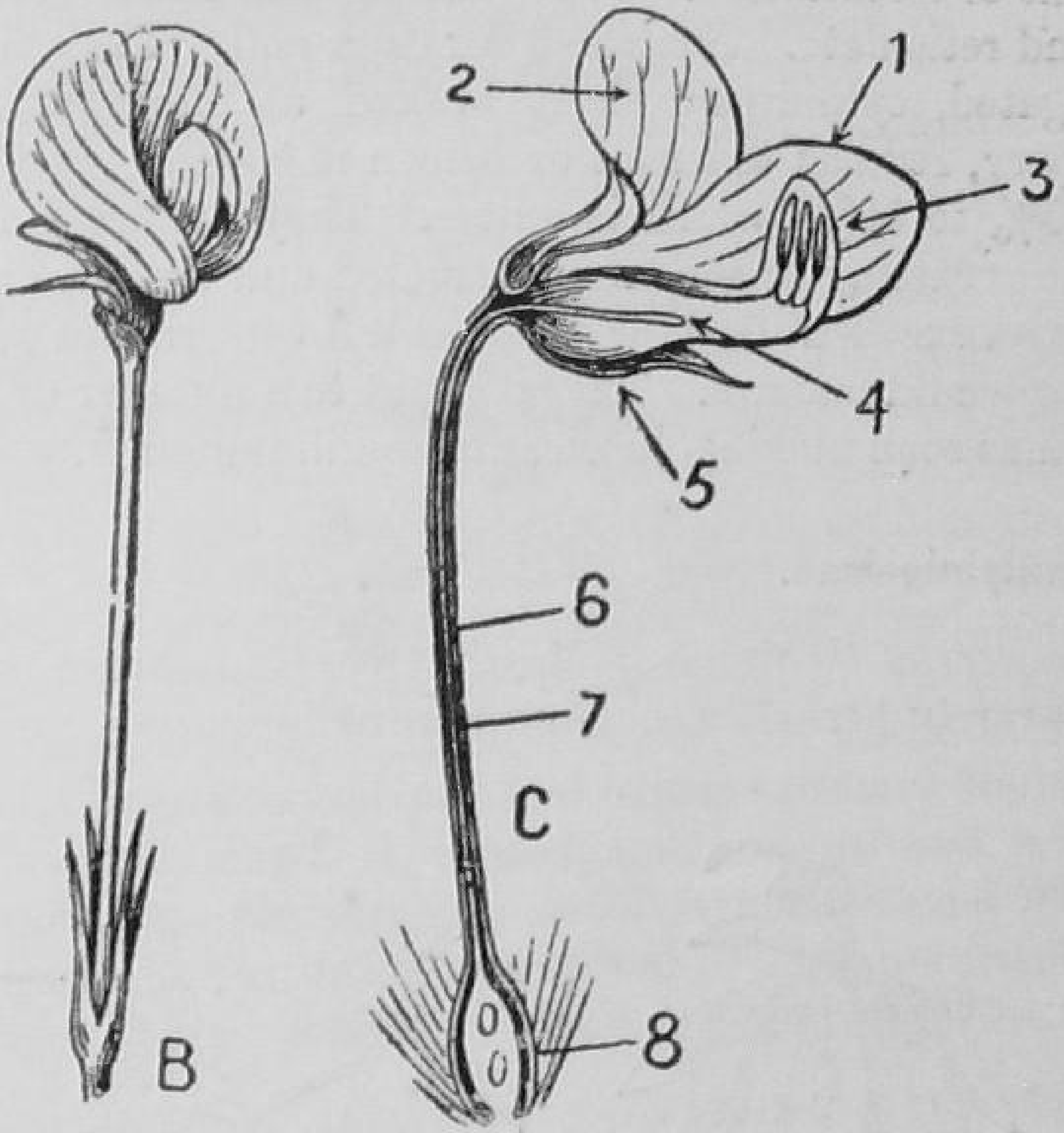

Fig. 366.—Groundnut—B & C—Flower and its parts.

axillary 1—3, sessile, orange yellow in colour. There are two sorts—fertile and sterile. Sterile flowers are most numerous in the upper axils; fertile most numerous towards the base of the plant and in the field may even be found below the ground surface. There is one bract and two bracteoles, the latter each split at their tips. *Calyx* tubular, long and slender and bears on its rim the lobes which are short and irregular. *Corolla* yellow, inserted on the rim of the calyx tube, standard broad, wings large, keel beaked. The 10 *stamens* are monadelphous and their filaments are fused for about two-thirds of their length. Sometimes only 9 are found. Only 8 are always fertile, the remaining two being sterile. The 8 fertile are dimorphic, 4 having elongated anthers and the other 4 rounded. *Pistil* single, sessile, marginal placenta, unilocular with 1—5 ovules, the wall somewhat constricted between the ovules; style curves upwards and is bearded near the tip.

Self-pollination is the rule. The gynophore is formed after fertilisation and pushes down the ovary into the soil, which condition is necessary for proper fruit setting. The gynophore is a result of the growth of the thalamus which is stimulated to develop as a result of fertilisation. *Fruit* oblong and indehiscent, surface ridged and reticulate. *Seeds* 1–3 for each pod. The mature seeds are elongated, cylindrical, short beaked at one end. *Seed coat* thin, papery, reddish to violet or brown in colour. Seeds are rich in oil (45% to 50%) which is edible. They are used either raw after slight roasting or the oil is extracted and used. The oil-cake is used as an excellent feed for cattle as it is very rich in protein and is also a splendid manure. The oil is put to a number of industrial uses, such as soap making, lubricants and illuminants.

15. Caesalpinioideae.

Characters of the family.—Mostly trees and shrubs, sometimes climbing, rarely herbs. *Leaves* pinnate or bipinnate, rarely simple

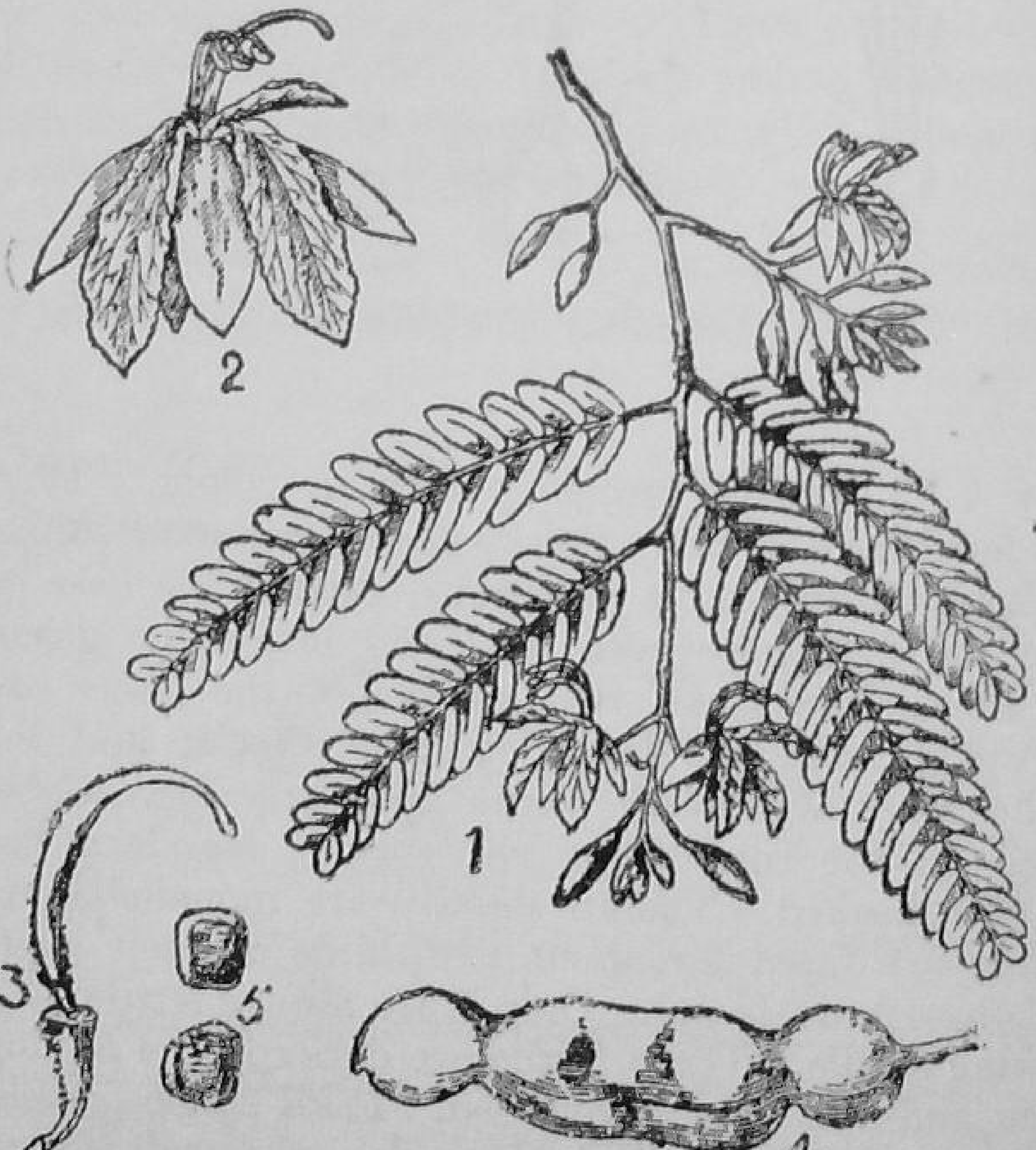

Fig. 367.—*Tamarindus indica*, L. 1. branch with leaves and flowers; 2. flower; 3. ovary and style; 4. fruit; 5. seeds.

or unifolioloate, stipulate, stipels mostly absent. *Flowers* showy racemose, rarely cymose; *zygomorphic ; Sepals* 5, mostly free, imbricate or valvate; *petals* 5, or fewer, *posterior* one inside, the others variously imbricate; *stamens*, mostly 10, rarely more than 10, free, sometimes united, *anthers* sometimes with porous dehiscence; *Ovary* superior, 1-celled; *fruit* dehiscent or indehiscent; *seed* with copious, thin or no endosperm.

Distribution.—Mainly Tropical.

Type :—(1) *Cassia auriculata*, L., or

(2) *Cassia siamea*, Lam.

The former is a shrub and the latter a tree. *Leaves* compound in both and paripinnate. *Stipules* large and semilunar in the first, and small and caducous in the second. *Flowers* in corymbose racemes, simple in *C. auriculata* and compound in *C. siamea. Calyx* of 5, free, unequal petaloid sepals, concave and quincuncially imbricate. *Petals* 5, clawed, imbricate in bud, with upper petal innermost. *Stamens* 10, some imperfect and 3 barren; *anthers* opening by *apical pores. Ovary* monocarpellary and 1 celled with many ovules. *Fruit* a flat legume. *Seeds* without endosperm.

Useful Plants.—

(1) *Cassia angustifolia*—The Indian senna, Pungative plant.
(2) *Tamarindus Indica*—Acid pulp used largely in India.
(3) *Saraca Indica* Lam—Flowers pretty.
(4) *Cassica fistula L*—Flowers pretty.
(5) *Cassia siamea*—Green manure.
(6) *Hardwickia binata*, Roxb—Timber.

16. Mimosoidae.

Characters of the family.—Trees or shrubs, very rarely herbs; *Leaves* mostly *bipinnate*, rarely simply pinnate; *Flowers* bisexual small, in *spikes* or *heads*, actinomorphic 3—6, usually 5 merous, *Calyx* tubular, *valvate*, rarely imbricate, 5 lobed or toothed; *Petals* valvate, free or united partially into a short tube; *Stamens* equal

PAPILIONACEAE.	CASSALPINIOIDEAE.	MIMOSOIDEAE.
1. Herbs, shrubs, rarely trees	Shrubs, Trees, rarely herbs	Mostly trees.
2. Simple, Pinnately trifoliolate or pinnate .	Pinnate or bipinnate.	Mostly bipinnate.
3. Flowers :		
(1) Racemes	Raceme or Corymb	Globose head or Spikes.
(2) Bisexual and Zygomorphic ..	Bisexual and zygomorphic	Bisexual and actinomorphic.
(3) Papilionaceous Corolla, posterior largest and outermost.	Posterior smallest and innermost ..	Regular and tubular corolla
(4) Stamens 10, mono or diadelphous (9 + 1).	Stamens 10 or fewer usually free.. ..	Stamens equal to the number of petals or numerous, free or monodelphous.
(5) Fruit—a legume	Legume	Legume.

in number to the sepals or very many, free or monadelphous; *anthers* small 2 celled, longitudinally dehiscing, often with a *deciduous gland* at the apex; *ovary* superior, 1-celled; *Fruit-a legume:* seeds with scanty or no endosperm.

Distribution.—Tropical and sub-tropical, many in dry regions.

Type:—*Acacia arabica,* Willd. (The Babul Tree.)

A small tree with numerous branches, bearing stipular spines. *Leaves* alternate, bipinnate; stipulate, with glands on the rachis, leaflets small. *Flowers* small, sessile, in globose peduncled heads. There are two bracteoles. *Calyx* campanulate with 5 short teeth. *Corolla* tubular, yellow with triangular lobes. *Stamens* indefinite, exserted. *Ovary* 1 celled with many ovules. *Fruit* stalked, compressed with soft white hairs and indented on both sides and between the seeds and hence moniliform or beaded.

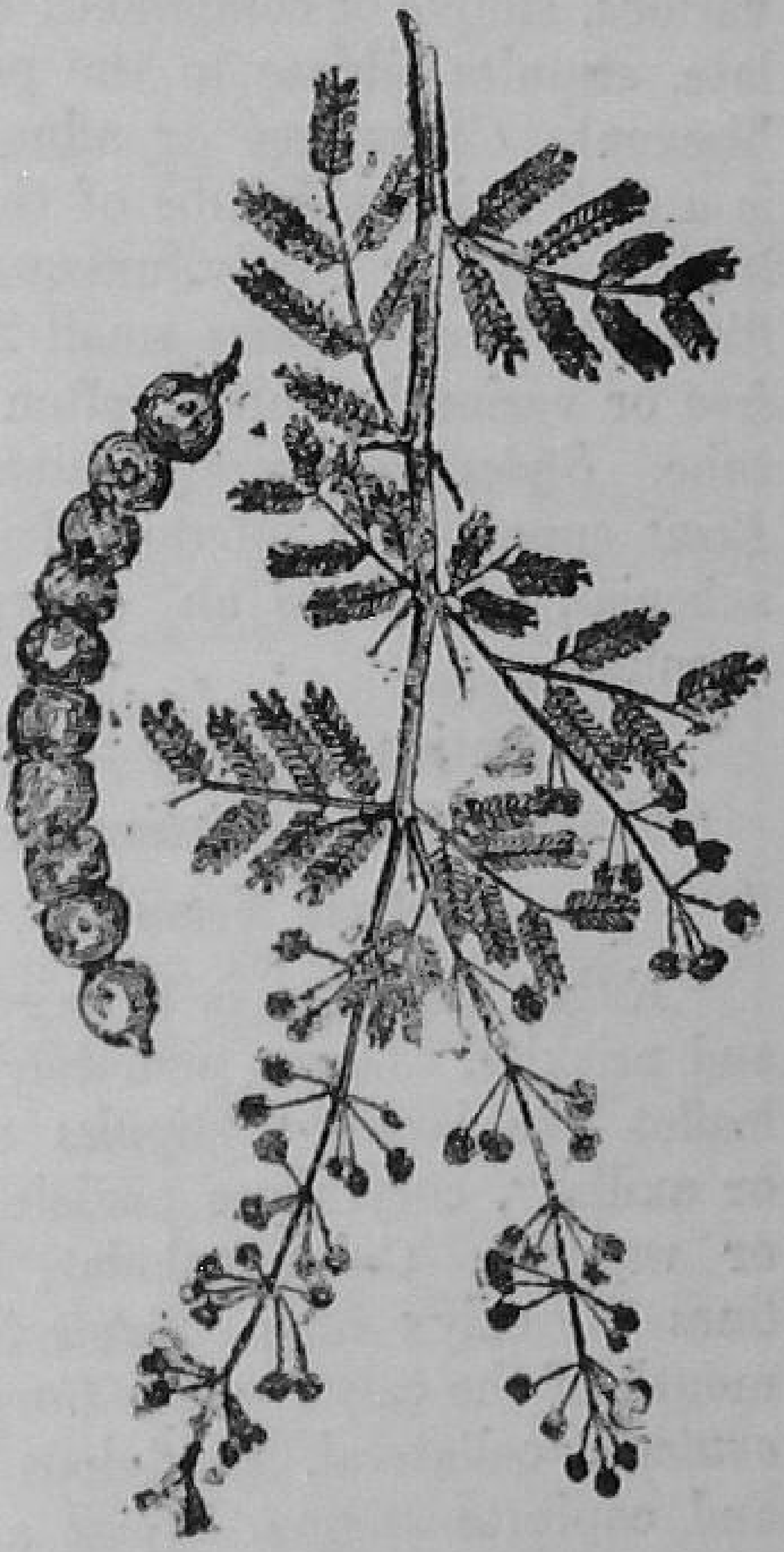

Fig. 368.—*Acacia arabica.* A twig with flower heads and a fruit.

Useful Plants.—

Several species of Acacia are useful—

(1) *Acacia concinna*—The fruit used as substitute for soap.

(2) *Acacia melanoxylon, etc.*—The wattles introduced from Australia.

(3) *Acacia arabia* Willed—Wood useful in many ways.

(4) *Xylia xylocarpa*—Timber very hard.

(5) *Prosopis juliflora*—Mesquit-forage, hedge.

(6) *Pithecolobium dulce*—Excellent fence, aril edible.

(7) *Enterolobium Saman*—Rain tree, avenue tree.

17. Rosaceae.

Characters of the family.—Trees, shrubs or herbs. *Leaves* various, simple or compound, alternate or opposite, mostly stipulate, stipules adnate to the petiole. *Flowers* actinomorphic and bisexual. *Calyx* free or adnate to the ovary, 5 lobed. There is a disk lining the tube of the calyx. *Petals* as many as calyx lobes, equal or rarely unequal, imbricate. *Stamens* numerous, filaments free; *anthers* small 2-celled. *Ovary* carpels 1 or more, free or variously united, often more or less adnate to the calyx tube. *Styles* free, rarely united; *Ovules* 2 or more in each cell. *Fruit* superior or inferior, drupaceous, pomaceous, follicular or achenial, sometimes an enlarged fleshy torus; *Seeds* exendospermous.

Distribution. Mainly temperate regions though cosmopolitan.

Types.—*Rubus ellipticus*, Sm.

Photinia Notoniana, W. & A.

Rubus ellipticus is a large straggling shrub with stiff hairs and prickles. *Leaves* pinnately 3 foliolate, wrinkled, the terminal leaflet the largest; *stipules* subulate. *Inflorescence* a terminal or axillary, corymbose panicle. *Flowers* white; bracteoles small or wanting. *Calyx* tubular, broad, lobes 5 persistent. *Disk* lines the calyx tube. *Petals* 5. *Stamens* many inserted on the mouth of the calyx tube. *Carpels* many on a convex receptacle; *ovules* 2 collateral, pendulous with a subterminal filiform style and capitate stigma. *Fruit* a cluster of small fleshy 1 seeded drupes crowded on the receptacle. *Seed* pendulous; cotyledons plano-convex, radicle superior.

Photinia Notoniana is a good sized tree having reddish-brown scaly bark, red close-grained wood. *Leaves* entire or toothed, simple, coriaceous; stipules subulate, deciduous. *Flowers* small white, in corymbose terminal panicles; bracts deciduous. *Calyx-tube* obconic, lobes 5 short persistent. *Petals* 5 spreading. *Stamens* 20, inserted on the mouth of the calyx. *Ovary* half-adhering, 2, rarely more celled; *styles* 2, rarely more, free or connate at the base; *Stigmas* truncate; *ovules* 2 in each cell, collateral, ascending. *Fruits* a small globose or ovoid drupe with 2 pyrenes each in a crustaceous endocarp and each with 2 seeds. *Seeds* obovoid, triquetrous or compressed; *testa coriaceous;* cotyledons plano-convex; radicle inferior.

Useful Plants.

(1) *Pyrus Malus*—The apple fruit tree.
(2) *P. communis*—The pear fruit tree.

(3) *Prunus persica*—The peach fruit tree.
(4) *P. domestica*—The plum fruit tree.
(5) *P. armeniaca*—Apricot nut.
(6) *P. Amygdalus*—Almond nut.
(7) *Fragaria Vesca, L*—Strawberry fruit.
(8) *Eriobotrya japonica Lindl.*—Loquat fruit.
(9) *Rosa spp.*—The roses flowers.

18. Combretaceae.

Characters of the family.—Trees or shrubs often scandent: *Leaves* opposite, alternate or rarely verticillate, simple; exstipulate. *Flowers* usually small, spikate or racemose, bisexual, rarely unisexual. *Calyx* tube adnate to the ovary limb 4—8 fid or lobed, valvate. *Petals* 4-5 or O small imbricate or valvate. *Stamens* 4—10 rarely more, filaments inflexed in bud, anthers versatile, disk epigynous. *Ovary inferior*, sometimes half-inferior, 1-celled, style simple, ovules 2—6 suspended from the apex of the ovary by slender stocks. *Fruit* often *winged*, rarely dehiscent, seeds pendulous, exendospermous.

Distribution.—Mainly in the Tropics.

Type.—*Terminalia Arjuna*, W. & A.

A large tree with smooth greenish white bark peeling off in large pieces. *Leaves* alternate or sub-opposite, simple and exstipulate, oblong to elliptic-oblong, with short petioles. There are also two glands at the base of the leaf close to the petiole, one on each side. *Flowers* in spikes, with short bracteoles. *Calyx* bell-shaped with 5 teeth. *Petals* not found. Stamens 10 inserted on a disk clothed with hairs. *Ovary* inferior, 1 celled with 2 or 3 pendulous ovules. *Fruit* a fibrous woody drupe, with five projecting wings. *Seed* single and without endosperm.

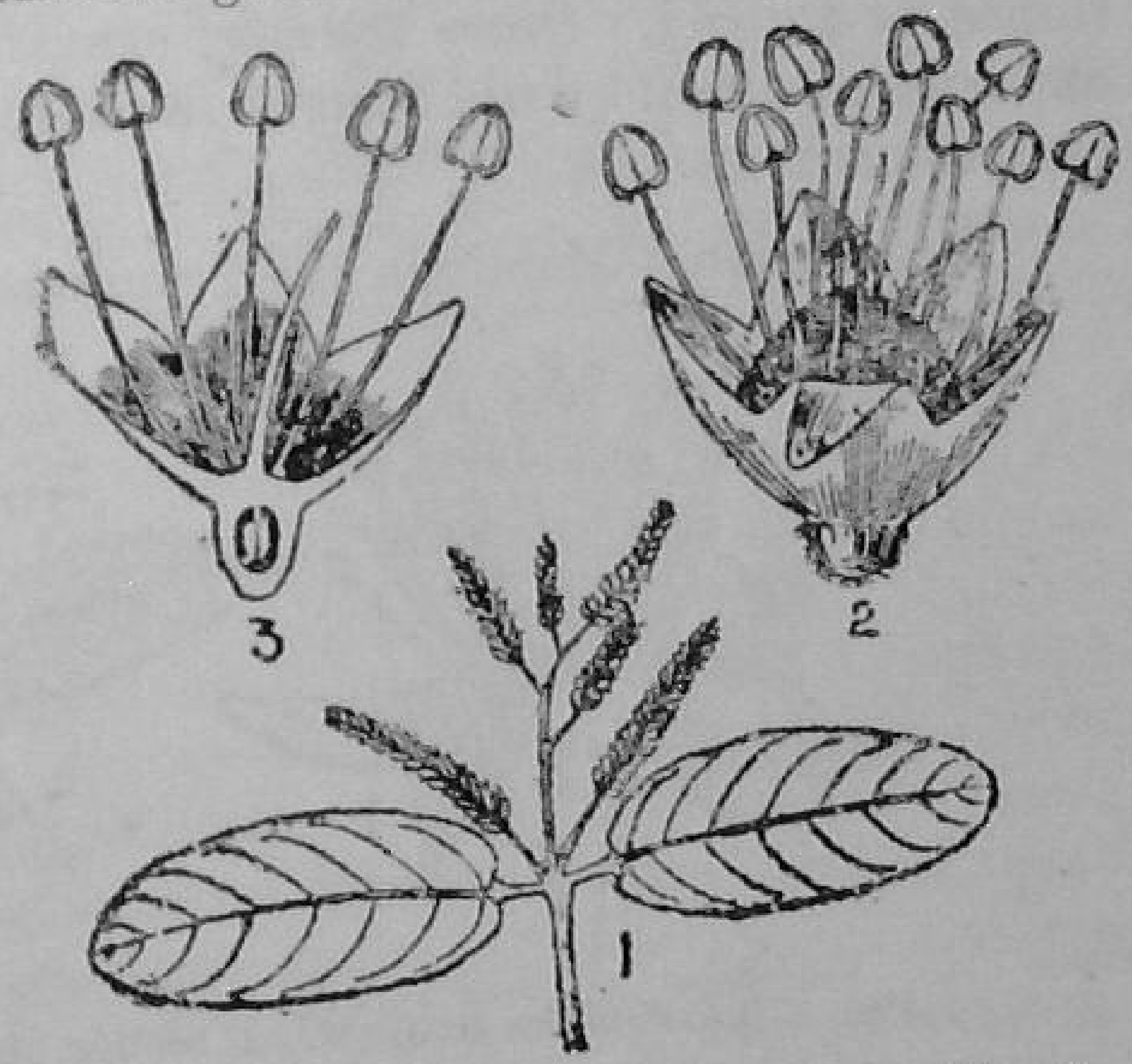

Fig. 369.—*Terminalia Arjuna.* 1. a bit of a branch; 2. a flower; 3. section of a flower.

If the type tree is not available *Terminalia Catappa*, L. may be taken as the type. In this tree branches are in whorls and grow long and bear short-stalked, obovate, large leaves, closely at the ends of twigs. Flowers are in simple spikes and the fruit is a drupe compressed ovoid and two-ridged.

Useful Plants.—

(1) *Terminalia Chebula*, Roxb. — Myrabolan tree — fruit valuable.

(2) *T. Arjuna*, W. & A.—Medicinal and a good avenue tree.

(3) *T. Belerica*, Roxb.—Medicinal.

(4) *Quisqualis indica*, L—Ornamental climber.

19. Myrtaceae.

Characters of the family.—Trees or shrubs. *Leaves* simple, mostly entire, opposite or rarely alternate, *glandular—punctate,* stipules O. *Flowers* actinomorphic, bisexual, usually in cymes. *Calyx* tube adnate to the ovary, lobes 3 or more, imbricate or valvate or irregularly split. *Petals* 4 or 5 free, rarely more, inserted on the margin of the disk lining the calyx tube, imbricate, falling away in one piece. *Stamens numerous, filaments long and slender,* 1 or more seriate, inflexed in bud ; *anthers* small 2-lobed, opening longitudinally or rarely by apical pores, the connective often tipped by a gland. *Ovary inferior*, syncarpous, 1 to many celled, axile placentation. *Fruit* berry or a capsule or indehiscent ; *seeds* exendospermous.

Distribution.—Mainly in the Tropics and Australia.

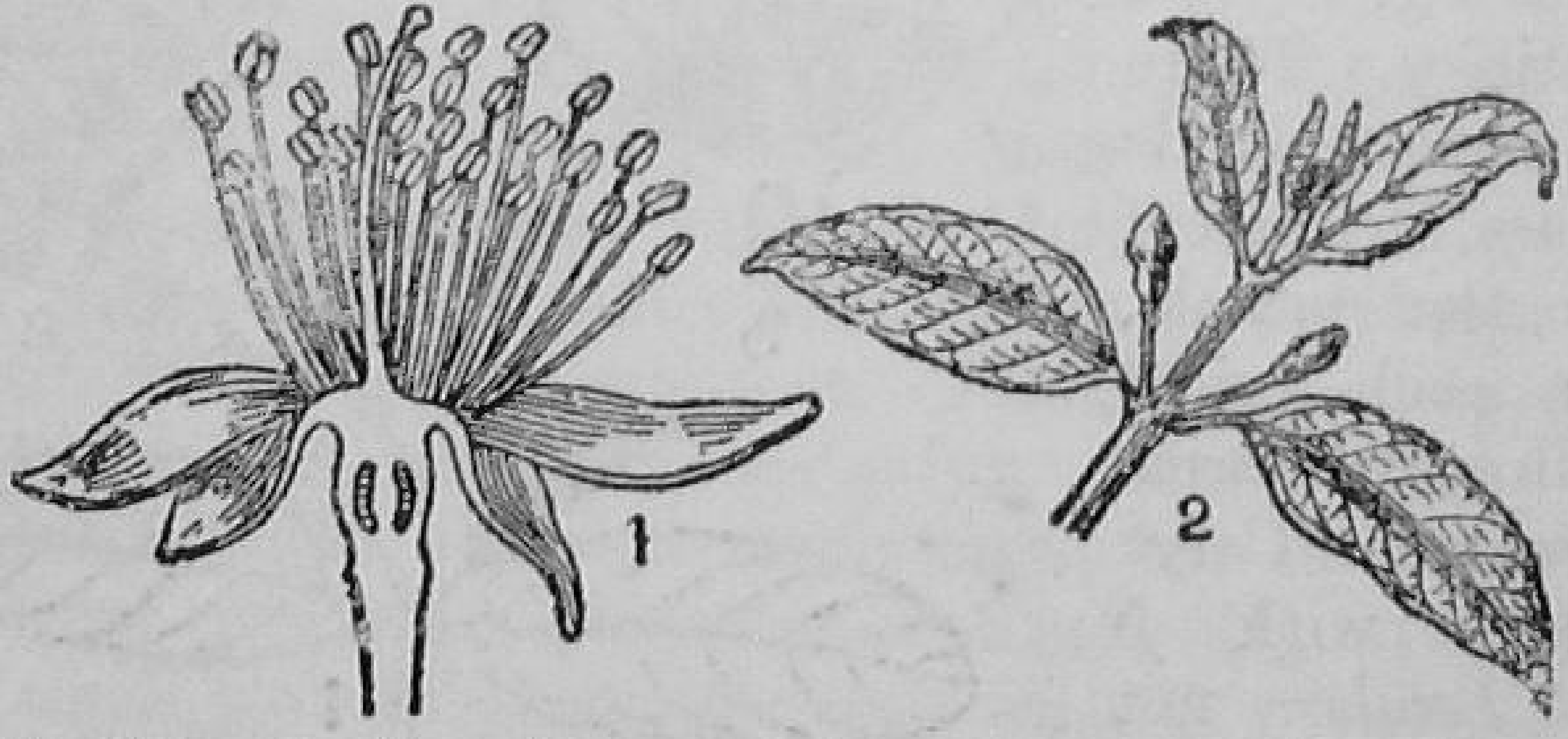

Fig. 370.—*Psidium Guajava*. 1. section of a flower ; 2. a bit of a branch.

Type.—*Psidium Guajava*, Linn. The guava. A small tree with the bark thin, smooth, greenish grey. It is a plant introduced from America and acclimatised in India. It is cultivated all over the province for the sake of its fruits. *Leaves* simple, opposite,

entire, not dotted. *Flowers* large, white 1 or few flowered, axillary clusters. *Calyx* lanceolate undivided in bud and separating valvately into 4–5 lobes in flower. *Petals* 4 or 5 free. *Stamens* many, inserted in several series on a disk which is prominent. *Ovary* many celled, ovules numerous in each cell. *Style* tubulate, *Stigma* Capitate. *Fruit* a globose yellow or reddish yellow berry, usually crowned by the calyx limb. *Seeds* many, hard-coated.

Useful Plants.—

(1) *Syzigium Jambolanum*, D. C.—Fruit edible, seeds of fodder value.

(2) *Psidium Guajava*, Linn.— Fruit.

(3) *Jambosa Vulgaris*, DC.—Rose apple, Fruit.

(4) *Eucalyptus spp.*—Yields Eucalyptus oil.

20. Cucurbitaceae.

Characters of the family.—Mostly herbs, rarely under-shrubs with plenty of watery juice, climbing by means of tendrils which are spirally coiled or prostrate or scandent. *Stems* hollow with bicollateral bundles, often scabrid. *Leaves* simple, alternate, fairly large, exstipulate, cordate at the base, entire or palmately lobed with coarse hairs. *Flowers unisexual*, monoecious mostly, dioecious rarely, actinomorphic, solitary or in racemes. *Male flower* calyx tubular 5 lobes, *Petals* gamopetalous, rarely free, 5 parts, imbricate or conduplicate valvate. *Stamens* free or variously united, generally 3, rarely 1—5, one anther always 1-celled the others 2 celled, cells straight or often sinuous, connective often produced. *Female flower* calyx tube adnate to the ovary and often produced beyond; *staminodes* usually not present. *Ovary inferior*,

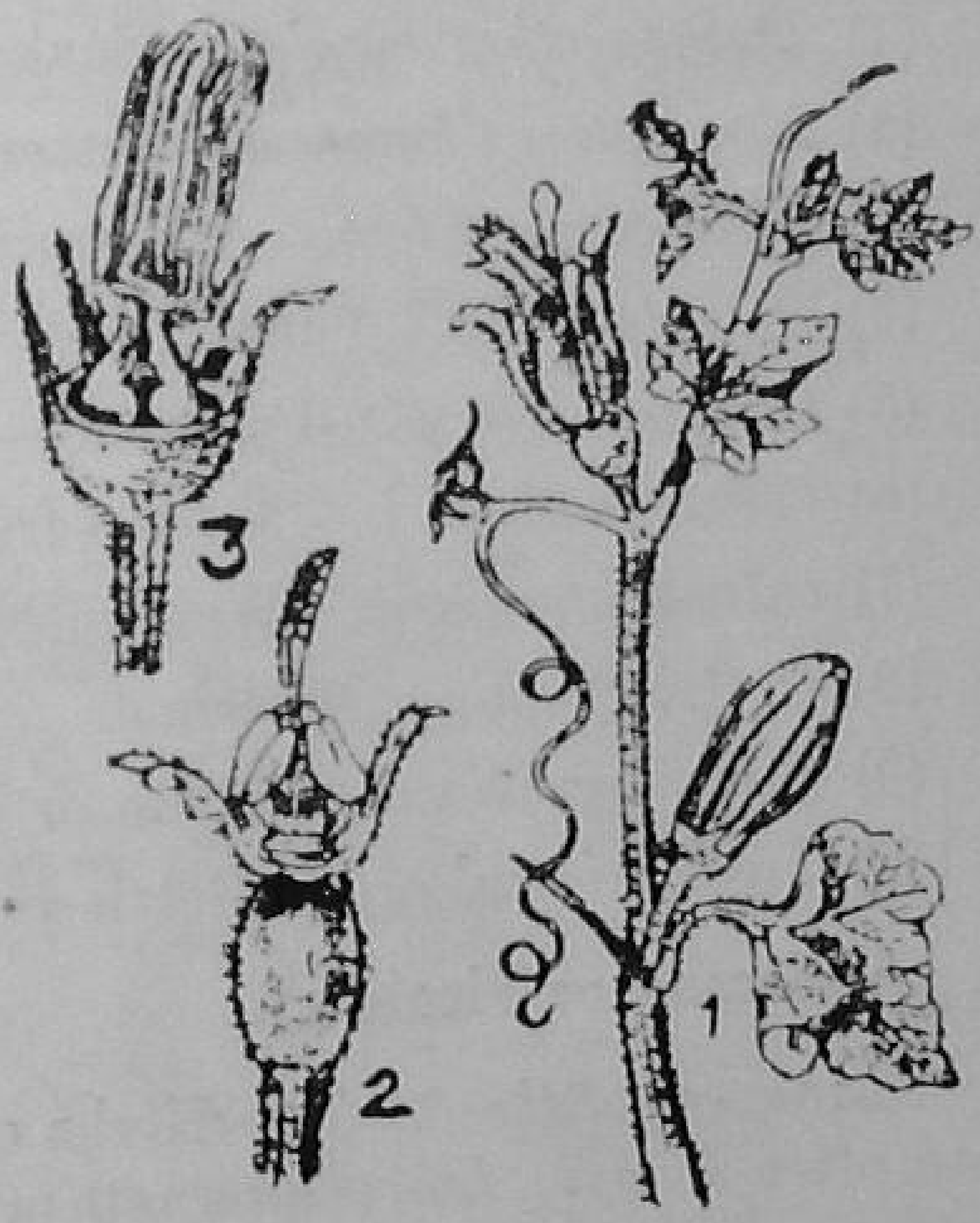

Fig. 371.—*Cucurbita moschata*. 1. branch with tendrils; 2. a female flower; 3. a male flower showing the stamens.

rarely free, placenta 3, parietal but often meeting in the middle. *Ovules* numerous, rarely few. *Style* simple or 3 fid. *Stigmas* thick, *Seeds* often flattened, exendospermous.

Distribution.—Tropics and sub-tropics.

Type.—*Coccinea indica,* W. & A. This is a common pretty tendril climber, easily obtained from hedges. *Leaves* variable, generally 5-angled with shallow sinuses but sometimes even on the same plant deeply 5-lobed. *Flowers* rather large, white, unisexual and dioecious. *Male flower* calyx tube campanulate, short 5 lobed. *Petals* campanulate shortly 5 fid. *Stamens* 3, *filaments* united in a column, *anthers* 1–1 celled, 2–2 celled, cells conduplicate. *Female flowers* calyx as in male but adnate to the ovary; *Petals* as in male. *Ovary* inferior. *ovoid,* 3 carpelled, ovules many in 3 parietal placentae. *Style* slender. *Stigmas* 3, *Fruit* an ovoid berry. *Seeds* ovoid, compressed; in female flowers, staminodes 3, oblong; pistillode in male flowers 0.

Useful Plants.—

(1) *Trichosanthes anguina.*—Snake-gourd—vegetable.

(2) *Momordica Charantia.*—Bitter-gourd—vegetable.

(3) *Benincasa cerifera.*—Ash-gourd—vegetable.

(4) *Cucurbita spp.*—Pumpkins—vegetable.

(5) *Cucumis sativus.*—Cucumber—fruit edible.

(6) *Cucumis Melo, L.*—Melon—fruit edible.

(7) *Citrullus vulgaris.*—Watermelon—fruit.

(8) *C. Colocynthis.*—Medicinal.

(9) *Luffa aegyptiaca.*—Loofah or bath sponge—vegetable.

(10) *Lagenaria vulgaris.*—Bottle-gourd—vegetable.

21. Aizoaceae or Ficoideae.

Characters of the family.—Herbs or low shrubs, erect or prostrate, often fleshy. *Leaves* alternate or opposite, sometimes minute, stipules may or may not be present. *Flowers* bisexual, actinomorphic. *Calyx* gamosepalous, free or adnate to the ovary, lobes 5—8 imbricate. herbaceous. *Petals* numerous or absent, 1-or more seriate, inserted in the calyx tube, linear. *Stamens* perigynous, many in several series or few, free or united into bundles, *anthers* 2 celled, small. *Ovary* superior or inferior, 1-several celled. *Ovules* solitary to many, basal, apical or axile. *Fruit* a capsule or nut like and drupaceous often with the persistent calyx.

Distribution.—Cosmopolitan, usually on sandy seashores.

Type.—The most troublesome weed *Trianthema portulcastrum*, L., a perennial prostrate weed is of this family. *Leaves*, opposite,

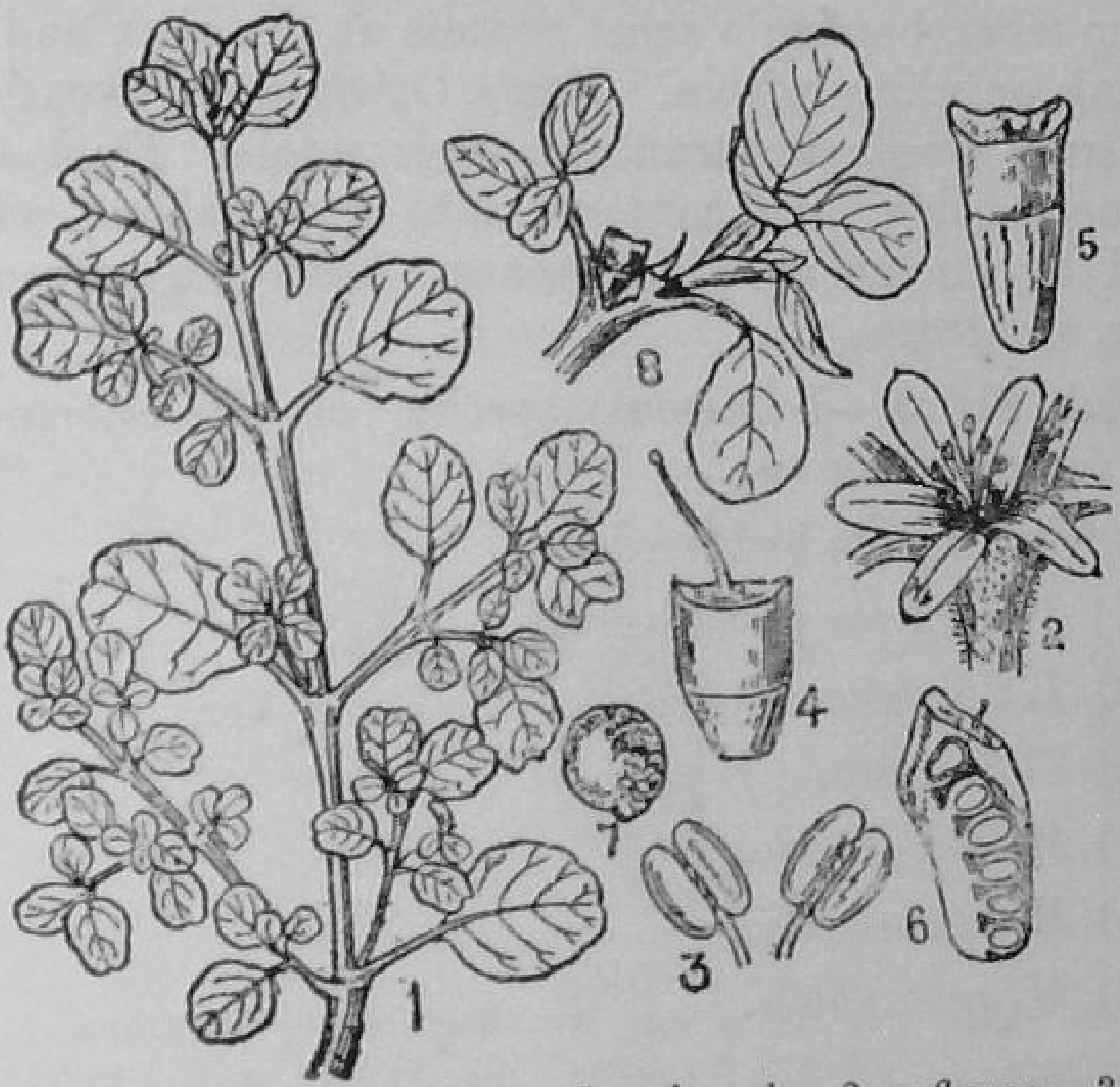

Fig. 372.—*Trianthema portulacastrum*. 1. a branch; 2. a flower; 3. stamens; 4. ovary; 5. fruit; 6. section of fruit; 7. seed; 8. flower bud at the node.

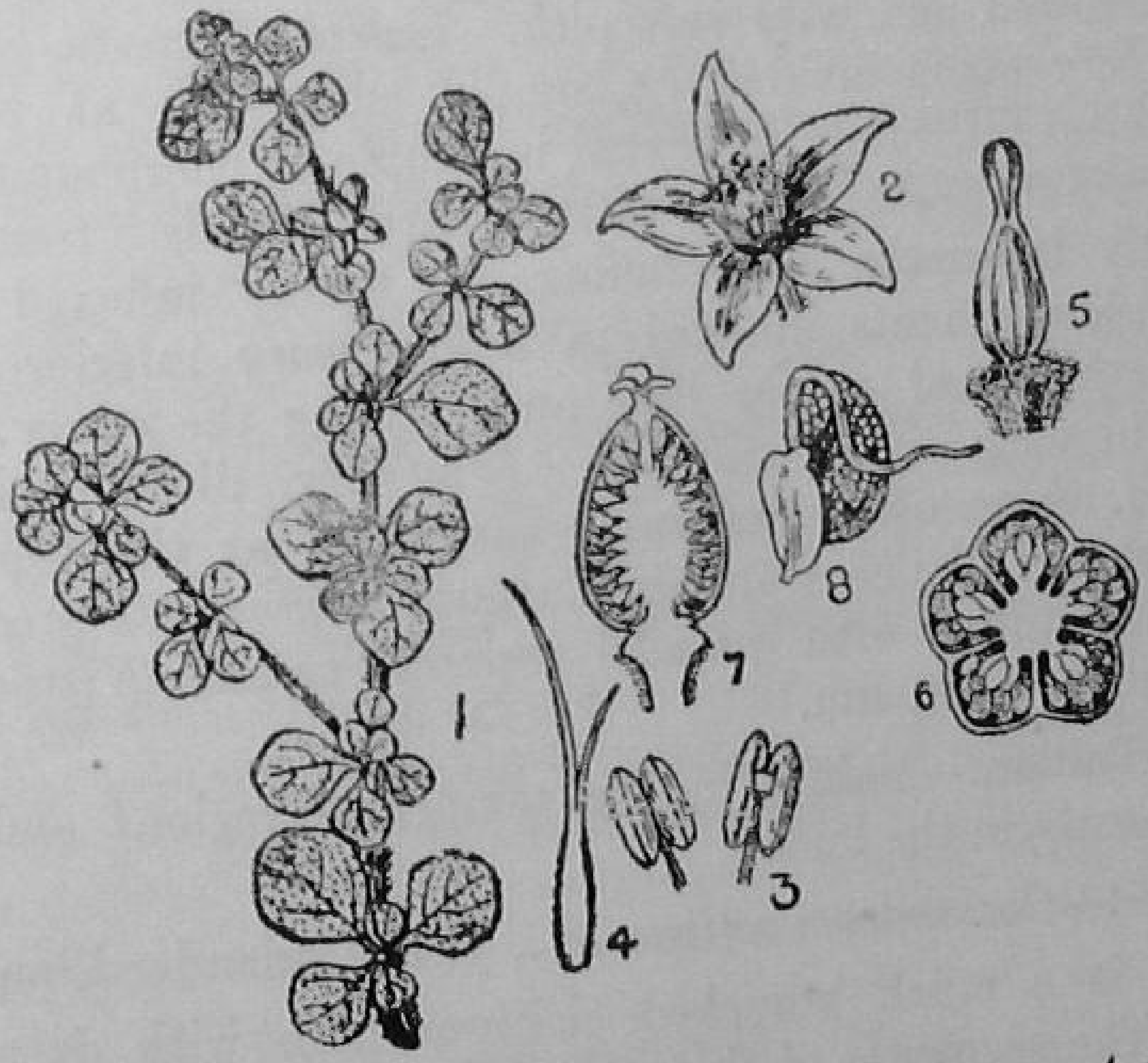

Fig. 373.—*Mollugo lotoides*. 1. a branch; 2. a flower; 3. stamens; 4. staminode; 5. an ovary; 6. a fruit cut across; 7. a fruit cut longitudinally; 8. a seed with the appendage.

(3) *Apium graveolens*—Celery—vegetable.
(4) *Peucedanum graveolens*—Dill seed.
(5) *P. sativum*—Parsnips.
(6) *Centella asiatica*—Elixir of life—Tonic.
(7) *Carum copticum*—Thymol.
(8) *Cuminum cyminum*—Cummin seed.

23. Rubiaceae.

Characteristics.—Trees, shrubs, rarely herbs. *Leaves* opposite or verticillate, simple, entire or rarely toothed, stipules often inter or intra petiolar, free or connate, sometimes leafy. *Flowers* mostly bisexual, actinomorphic and rarely zygomorphic. *Calyx* 4 to 5 gamosepalous adnate to the ovary ; *Corolla* epigynous more or less tubular, lobes 4-10, contorted, imbricate or valvate, *Stamens* as many as corolla lobes and alternate with them. Epipetalous. *Ovary inferior* 2 or more celled with axile placentation, style slender variously lobed. *Ovules* 1 to many; *Fruit* a capsule, berry or drupe ; *seeds* generally endospermous.

Distribution.—Mostly tropical though distributed all over the world.

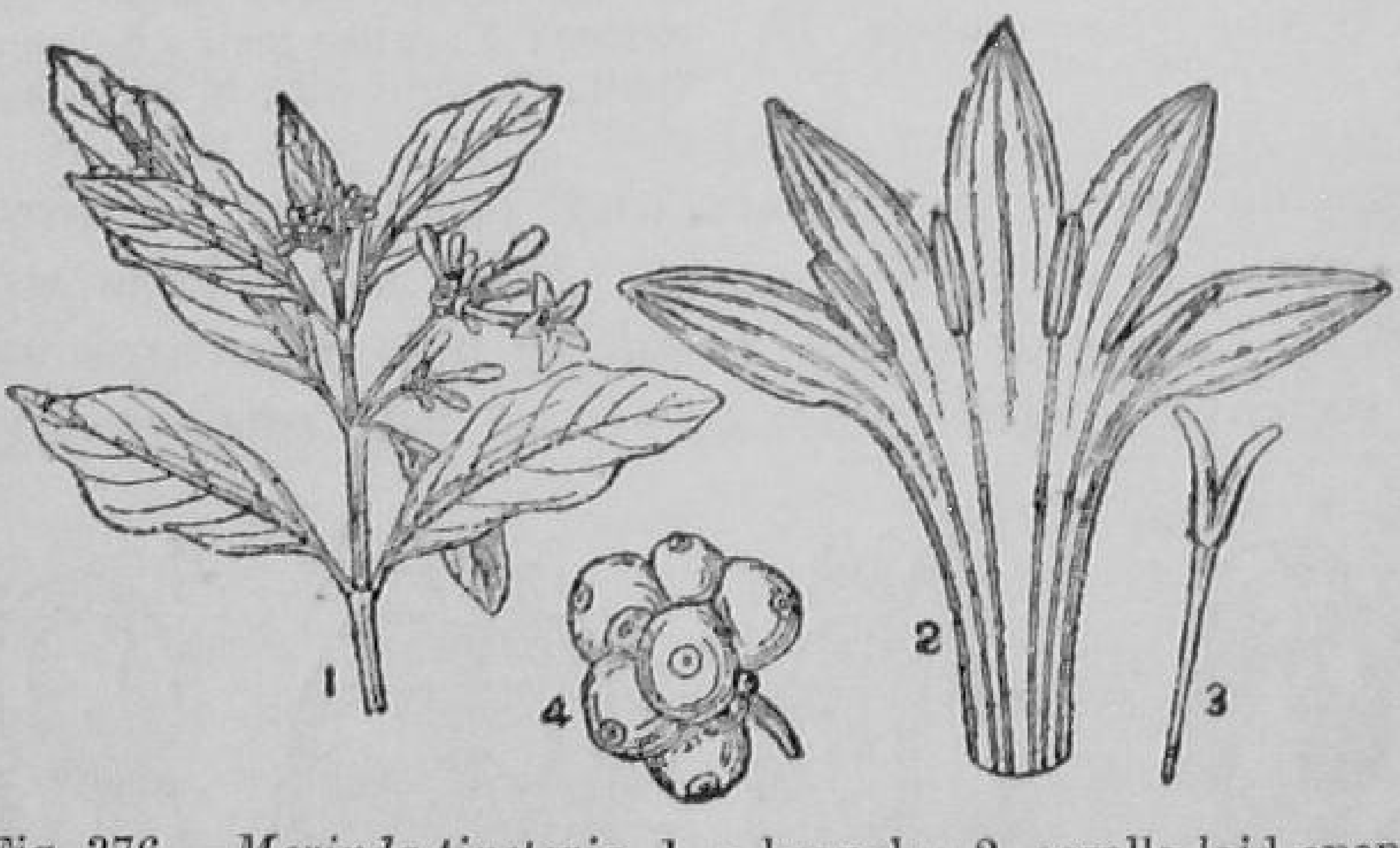

Fig. 376.—*Morinda tinctoria*, 1. a branch ; 2. corolla laid open to show the epipetalous stamens ; 3. style ; 4. a fruit.

Types :—*Morinda tinctoria*, Roxb.,
Oldenlandia umbellata, L.

Morinda tinctoria is a tree with thick, white, irregularly furrowed bark, and crooked branches. *Leaves* opposite, simple, shortly petioled, with connate interpetiolar stipules, glabrous, elliptic-oblong. *Flowers* white, in heads, on leaf-opposed long peduncles.

Calyx of all the flowers fused. *Corolla* tubular, 5-lobed, superior. *Stamens* 5 epipetalous. *Ovary inferior* 2 or 4-celled. *Fruit* globose, fleshy, consisting of the fused enlarged calyces of all the flowers, with many druplets or pyrenes. *Seeds* with emdosperm.

Oldenlandia umbellata, L., is an annual weed with many branches. *Leaves* linear, opposite with the interpetiolar stipules cut into bristles. *Flowers* in cymose umbels, on long axillary peduncles, tetramerous. *Ovary* inferior, 2 celled with many ovules. *Fruit* a globose capsule, with persistent calyx-teeth on its top. *Seeds* are small and numerous.

Useful plants—

1. *Coffea arabica* .. Coffee plant.
2. *C. Robusta* .. Do.
3. *Cinchona spp.* .. Quinine.
4. *Psychotria Ipecacuanha.* . Ipecacuanha Root.
5. *Pavetta spp.* .. Ornamental.
6. *Ixora spp.* .. Do.

24. Compositae.

Characteristics.—Herbs, shrubs, rarely trees or climbers. *Leaves* alternate or opposite, simple or variously divided. Stipules absent. *Flowers* crowded into *heads* (*Capitula*) invested by an involucre of one or more series of free or united bracts, sometimes the head is a compound head made up of partial heads made up of one or more flowers; receptacle bracteate amongst the flowers, usually conical, rarely elongated or hollowed out. *Flowers* bisexual; unisexual and monoecious or rarely dioecious, the outer ones often ligulate (**ray florets**), the inner ones tubular (**discoid florets**), *Calyx* usually much modified and thread like (pappus) rarely dry and chaffy, epigynous, *Corolla* epigynous gamopetalous, 4-5 fid, valvate, actinomorphic or zygomorphic, rarely bilabiate. *Stamens* 5 or rarely 4, epipetalous, mostly included in the Corolla tube; *filaments* free from each other; *anthers* connate (*syngenesious*) into a short tube, 2 celled, longitudinally opening. *Ovary inferior*, 1-celled, 1-ovuled; *style* mostly bifid or bilobed with various forms of collecting hairs which serve to brush out the pollen. *Ovules* erect from the base. *Fruit achene*, sessile, sometimes beaked; *seed* exendospermous.

Distribution.—Cosmopolitan and therefore all over the world

Type :—*Vernonia cinerea*, Less.

A perennial herb with very variable leaves, though usually ovate or lanceolate and with undulately toothed margin. *Heads* in terminal lax corymbs. *Flowers* all tubular and bisexual. The involucral bracts are in many series, linear-lanceolate. *Corolla*

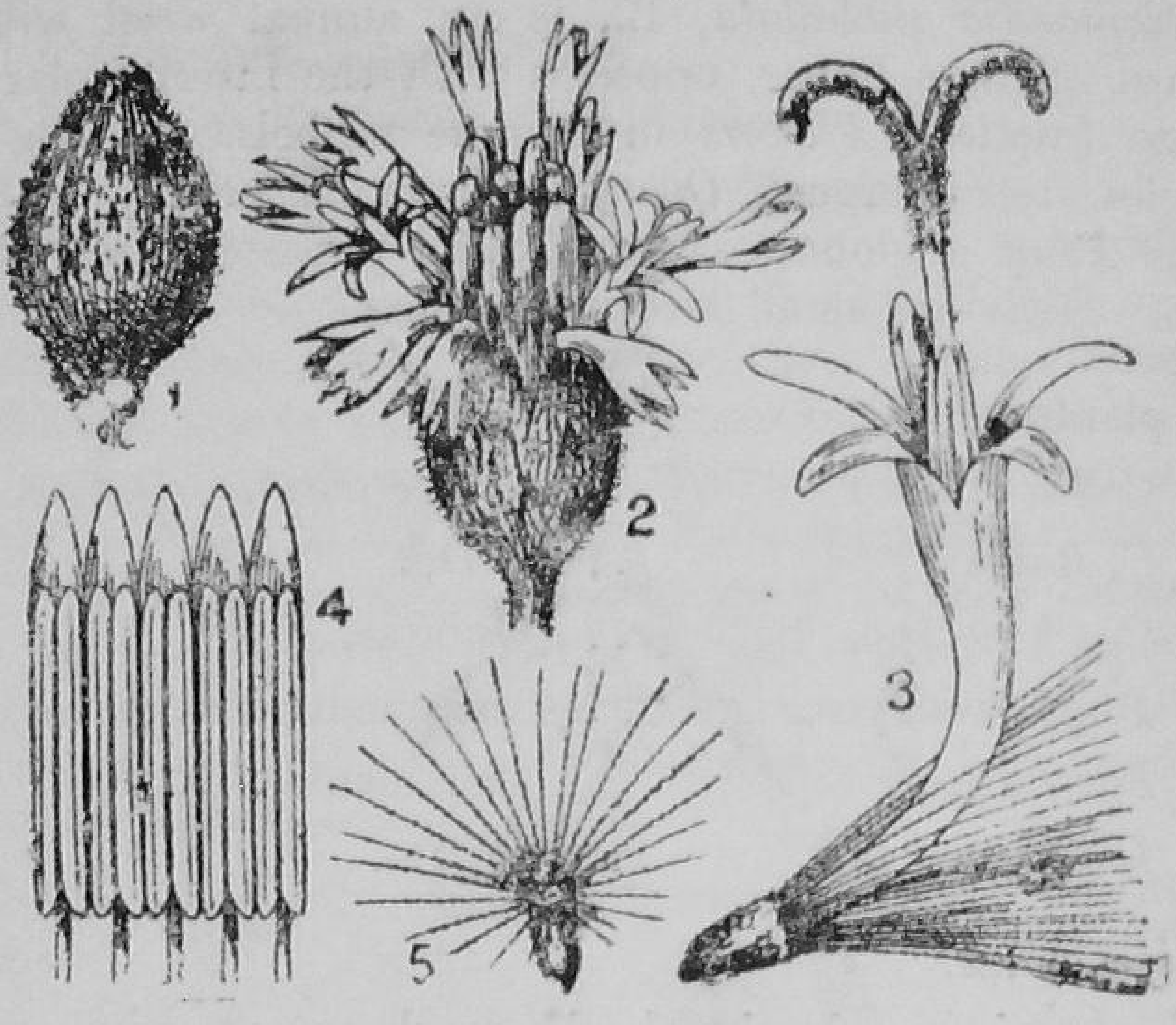

Fig. 377.—*Vernonia cinerea*. 1. a young flower head; 2. a flower head with flowers open; 3. a tubular flower; 4. anthers; 5. an *achene*.

narrowly tubular, pink. *Stamens* 5 with syngenesious anthers epipetalous. *Achenes* 4 or 5 angled clothed with short hairs and 5 rows of white pappus hairs.

The common weed *Tridax procumbens*, L., an introduced South American weed, may also be examined as a type.

This is a perennial herb with straggling hairy branches some of them ending in heads. *Leaves* opposite, simple, ovate or ovate-lanceolate, irregularly coarsely toothed and hairy on both surfaces. *Heads* on long peduncles, solitary, heterogamous and rayed. Involucral bracts outer shorter and hairy, *Receptacle* flat, paleate. Ray flowers cream-colour or light yellow, ligulate, deeply 3 partite, female. *Disk* flowers bisexual tubular. *Corolla* of tubular flowers bell-shaped, 5 lobed. *Stamens* 5, epipetalous with syngenesious anthers. *Ovary* inferior. 1-celled, 1-ovuled. Stylar arms of tubular flowers hairy on the inner surface. *Fruit* is an oblong achene, silky hairy and crowned by the persistent feathery bristles of the pappus.

The plants of this family are very aggressive and successful in occupying the land. **The compact massing of the flowers into**

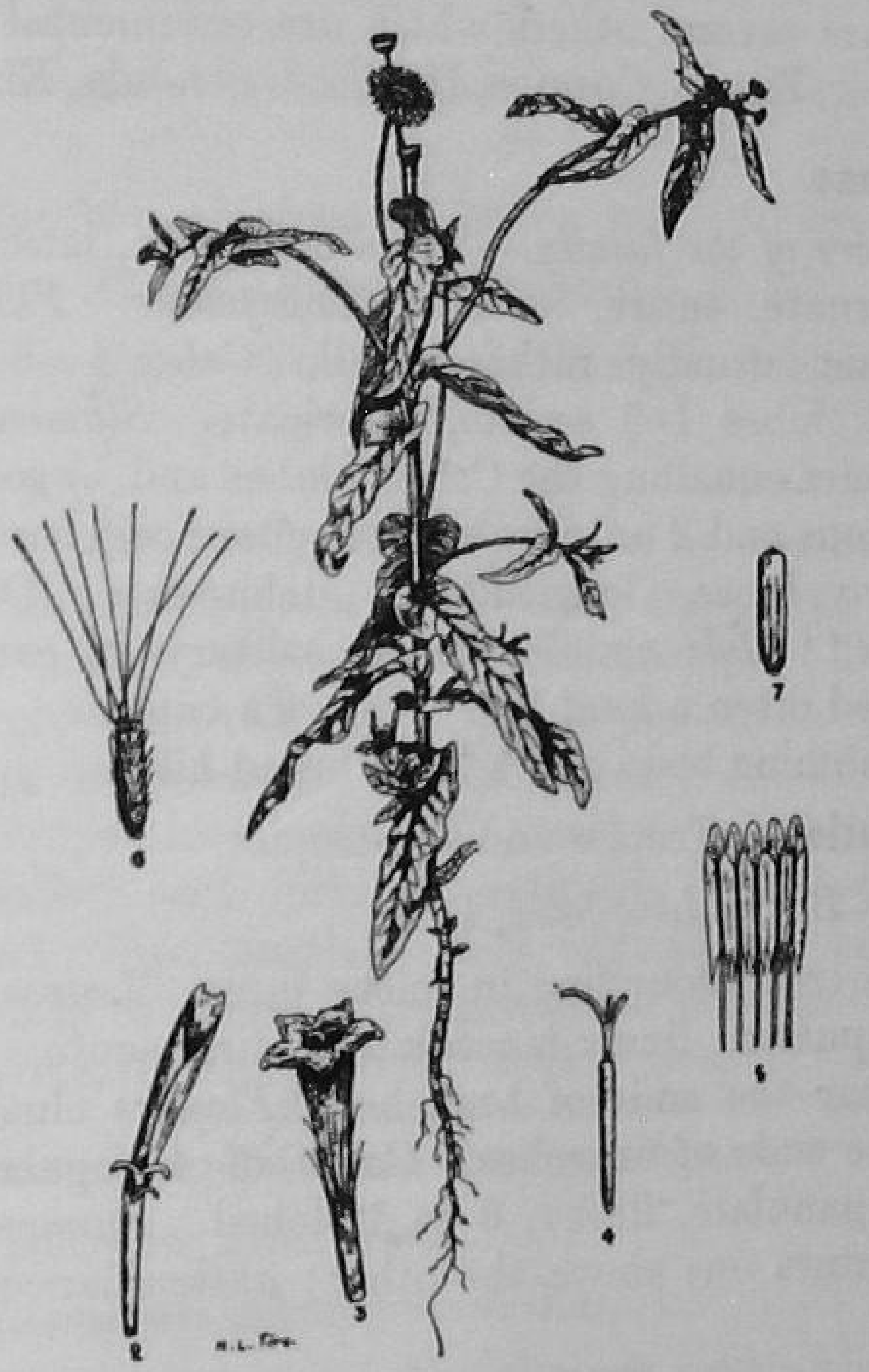

Fig. 378.—*Vicoa indica, DC.* 1. Entire plant; 2. Female floret. (Ray); 3. Bisexual floret; 4. Female floret; 5. Stamens; 6. Achene of Bisexual fewer with pappus; 7. Achene of ray floret with no pappus.

heads, the simple effective floral mechanism ensuring protection of honey and pollen and cross-pollination until the last possible moment and the pappus-bearing achenes are favourable factors which have helped this family to successfully thrive in the present day world.

Useful Plants

(1) *Helianthus tuberosus*—Jerusalem Artichoke—vegetable.

(2) *Lactuca spp.*—Lettuce.

(3) *Carthamus tinctorius*—Safflower—oilseed.

(4) *Guizotia abyssinica*—Nigar-seed—for oil.

(5) *Artemisia Cina*—Santonin.

(6) *Cichorium Intybus L.*—Chicory.

There are several others which are ornamental garden plants like Sunflower, Zinnia, Cosmos, Dahlia, Calendula, Eupatorium, etc.

25. Sapotaceae.

Characters of the family.—Trees or shrubs, laticiferous, *Leaves* simple, alternate, entire, leathery, *exstipulate*. *Flowers* bisexual, actinomorphic, usually rather small. *Calyx* 4—8 lobes, *Corolla* 4—8 lobed, lobes 1–2 seriate, imbricate. *Stamens* epipetalous, the fertile ones equalling the *Corolla* lobes and *opposite to* them or more numerous and 2 or more seriate, *staminodes sometimes present.* *Anthers* two lobes, longitudinal dehiscence. *Ovary* superior several celled ; *style* simple ; *ovules* solitary in each cell. *Fruit* 1-many celled often a hard berry, rarely a capsule. *Seeds* with a bony often shining testa and a large broad hilum.

Distribution.—Tropics and sub-tropics.

Type :—*Bassia longifolia*, L.

A large tree abounding in milky juice. *Leaves* simple, alternate, ex-stipulate, linear-lanceolate, entire, acute, glabrous and clustered near the ends of branches. *Flowers* clustered like the leaves at the ends of branches. *Calyx* of 4 sepals in 2 whorls. *Corolla* campanulate, fleshy, 6 to 12-lobed. *Stamens* epipetalous, 6 to 20 in 2 rows one above the other ; *anthers* lanceolate with the

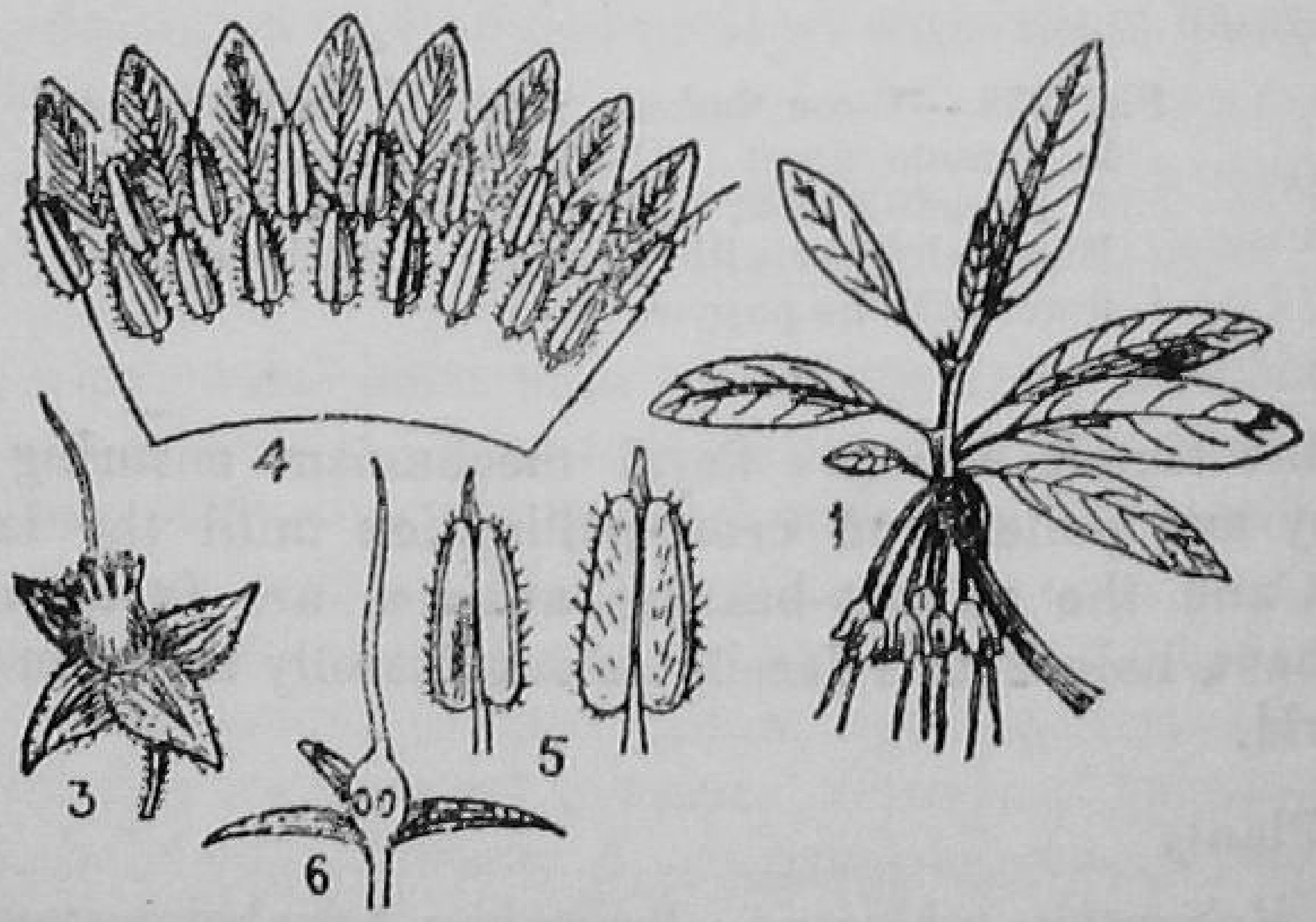

Fig. 379.—*Bassia longifolia.*—1. a branch ; 3. a flower ; 4. corolla and stamens ; 5. stamens ; 6. ovary cut longitudinally.

connectives produced above the anthers. *Ovary* 6 or more-celled, clothed with fine hairs. *Fruit* a berry with 1 or 2 seeds. *Seeds* with polished testa and non-endospermic.

Useful Plants.—

(1) *Achras Sapota*—Sapodilla plum or the Sapota fruit largely cultivated.

(2) *Bassia latifolia*—Mahwa or Mowa tree—oil seed.

(3) *Mimusops Elengi*—Flowers fragrant.

(4) *Palaquium Gutta*—Gutta-percha, Malaya Peninsula.

26. Oleaceae.

Characters of the family—Trees, shrubs or climbers. *Leaves opposite*, rarely alternate, simple or *pinnate, exstipulate.* *Flowers* hermaphrodite, rarely unisexual, actinomorphic. *Calyx* lobed or dentate, rarely absent, *Corolla* petals present or absent, free or united, often 4, imbricate or induplicate, valvate. *Stamens* hypogynous or epipetalous, usually 2, rarely 4. *Anthers* apiculate, 2 celled, *cells back to back* opening lengthwise, disk absent. *Ovary* superior 2-celled ; *style* simple with a capitate or bifid stigma. *Ovules* usually 2 in each cell, axile, pendulous or ascending. *Fruit* capsular, berrylike, or drupaceous ; *seeds* endospermous.

Distribution.—Temperate and Tropical regions.

Type :—*Nyctanthes Arbor-trists*, L.

Jasminum angustifolium, *Vahl.*

Nyctanthes Arbor-tristis is a small tree rough all over with stiff whitish hairs. *Leaves* ovate, acute, rough above, hairy beneath, entire, two to three inches long. *Flowers* in small bracteate heads in branching cymes at the ends of branches, fragrant. *Calyx* 4 to 9 lobed. *Corolla* salver-shaped, $\frac{1}{2}$ in. long ; lobes 4 to 8, spreading white, contorted in bud ; *tube* orange coloured. *Capsule* somewhat circular, compressed separating into two flat one-seeded carpels. *Seeds* flat, single in the carpel.

Jasminum angustifolium is a climbing shrub, with their tender branches covered with minute soft hairs. *Leaves* ovate, acute, glabrous, nerves few and obscure, $1\frac{1}{2}$ to 2 in. long, those on the younger branches smaller, leaf stalks $\frac{1}{8}$ in. long. *Flowers* single or cymes of two or three. Flower stalk slender $\frac{1}{2}$ to $\frac{3}{4}$ in. long. *Calyx* 7 to 9 toothed. *Corolla* fragrant, white, sometimes purplish outside in the bud ; *tube* $\frac{1}{2}$ to $\frac{3}{4}$ in. long ; lobes 8 to 10, lanceolate, $\frac{1}{2}$ to $\frac{5}{8}$ in. long. *Fruit* ellipsoidal,unsymmetrical, $\frac{1}{3}$ in. long.

Useful Plants.—

(1) *Jasminum spp.*—Ornamental, flowers scented.

(2) *Nyctanthes Arbor-tristis, L*—ornamental flowers—fragrant

(3) *Olea europea L.*—Olive tree yielding olive oil.

27. Apocynaceae

Characters of the family—Trees, shrubs or climbers *Leaves* opposite or whorled, rarely alternate, simple, entire, *stipules absent. Flowers* bisexual, actinomorphic ; *Calyx* often *glandular inside,* lobes 5, imbricate, *Corolla* tubular variously shaped, lobes *contorted, imbricate. Stamens* 5 or rarely 4, attached to the tube, *anthers* often sagittate, free or connivent around the stigma, rarely adherent to the latter, 2 celled, *connective often produced at the apex*, pollen *granular*, disk usually present, annular, cupular or of separate glands. *Ovary* superior, 1-celled with 2 *parietal* placentas or 2-celled with the placentas adnate to the septa or carpels 2 and free or connate at the base with vertical placentas in each carpel. *Style* 1, split at the base or entire, *Ovules* 2 or more in each carpel. *Fruit* indehiscent or of 2 separate carpels, berrylike, drupaceous or follicular. *Seeds* endospermous, winged or appendaged with long silky hairs.

Distribution.—Tropics and sub-tropics.

Type :—*Lochnera rosea*. R.

An erect or procumbent perennial herb, common all over the province especially along the coast. It is probably introduced from the West Indies. It is cultivated in the gardens and also run wild. *Leaves* petiolate, exstipulate, simple, opposite, decussate, elliptical or obovate, entire, *Flowers* axillary or in short terminal cymes, bisexual, complete, regular, hypogynous. *Calyx* 5, gamosepalous ; *Corolla* 5, gamopetalous, hypocreateriform, throat constricted, lobes broad spreading, twisted, coloured rose. *Stamens* 5, epipetalous, included within the corolla tube. *Ovary* ovaries 2, superior, unilocular with few ovules, placentation marginal ; *style* filiform, stigma thickened, ring like, two large honey glands are present each on the side of an ovary. *Fruit* 2, slender, erect or spreading follicles.

Useful Plants.—

(1) *Landolphia spp.*—Landolphia rubber.

(2) *Funtumia elastica*—silk rubber tree.

(3) *Lochnera rosea*—ornamental.

(4) *Nerium odorum*—ornamental.
(5) *Thevetia neriifolia*—ornamental.
(6) *Plumeria acutifolia*—ornamental.
(7) *Allamanda Cathartica*—ornamental.
(8) *Carissa carandas*—fruit edible.

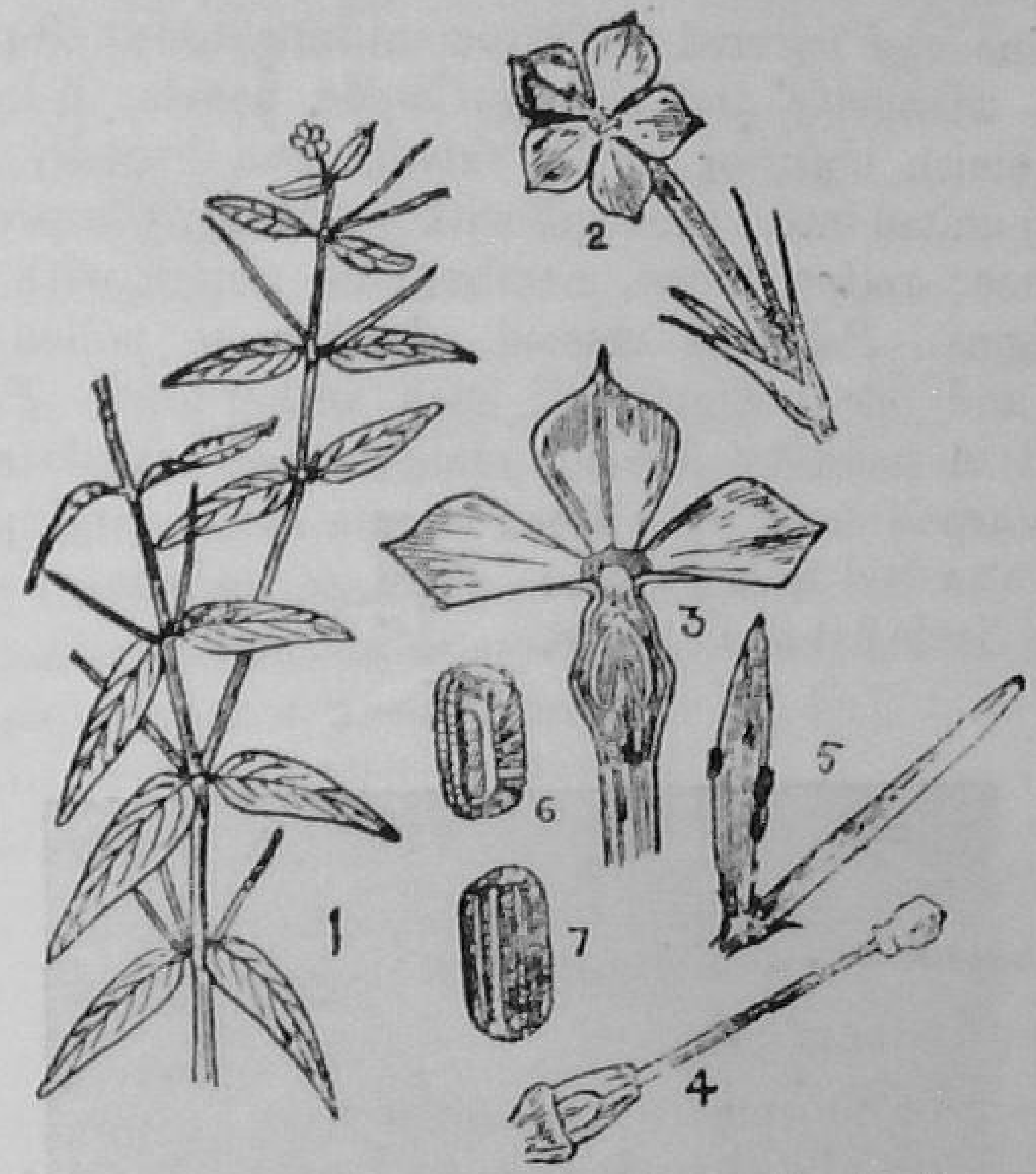

Fig. 380.—*Lochnera pusilla*. 1. a branch; 2. a flower; 3. section of the flower; 4. pistil; 5. follicles; 6 and 7. seeds.

28. Asclepiadaceae.

Characters of the family.—Perennial herbs, undershrubs or shrubs, sometimes *climbing*. *Leaves* opposite or verticillate, laticiferous, simple, exstipulate. *Flowers* cymose generally bisexual, actinomorphic. *Calyx* lobes 5 imbricate or open, *Corolla* 5 lobed, lobes contorted or valvate, *Corona simple or 5 or mere scales either adnate to the corolla tube or the stamens or to both*; *stamens* 5, mostly inserted at the base of the corolla, filaments separate or united into a tube, anthers connivent around the stigma and often adnate to it, 2 celled, *pollen in masses* (*pollinia*); *disk* absent, *Ovary* 2 distinct carpels, superior, placentas ventral; *styles* 2, distinct, but united at the apex in a common stigma, the stigma thick and often disc like. *Ovules* numerous. *Fruit* 2 divergent *follicles*; *seeds* comose with silky hairs.

Distribution.—Mainly in the warm regions—very abundant in S. Africa.

Type :—*Calotropis gigantea*, R. Br.

A shrub abounding in milky juice common in waste places. The leaves and stems are covered with oppressed white cottony tomentum. *Leaves* large, opposite, exstipulate, shortly stalked, oblong or elliptic-oblong, thick ; entire. *Flowers* in lateral umbels. *Pedicel* fine and covered with tomentum. *Calyx* 5-partite and segments triangular and short. *Corolla* rotate, 5-lobed ; lobes pink or bluish pink, or white, valvate and broadly triangular. *Stamens* 5 united into a tube and with 5 laterally compressed plate-like coronas ; *anthers* broad, membranous, united with the pentagonal stigma. *Pollen* is massed together as pollen-masses or pollinia, and one pollinium in each anther-lobe. *Pollinia* are connected in pairs by 5 black stalks called **translators.** *Ovary* 2-celled, carpels free ; *styles* free ; stigma large, and pentagonal, peltately attached to the styles. *Fruit* of inflated follicles 1 or rarely 2. *Seeds* flat and comose.

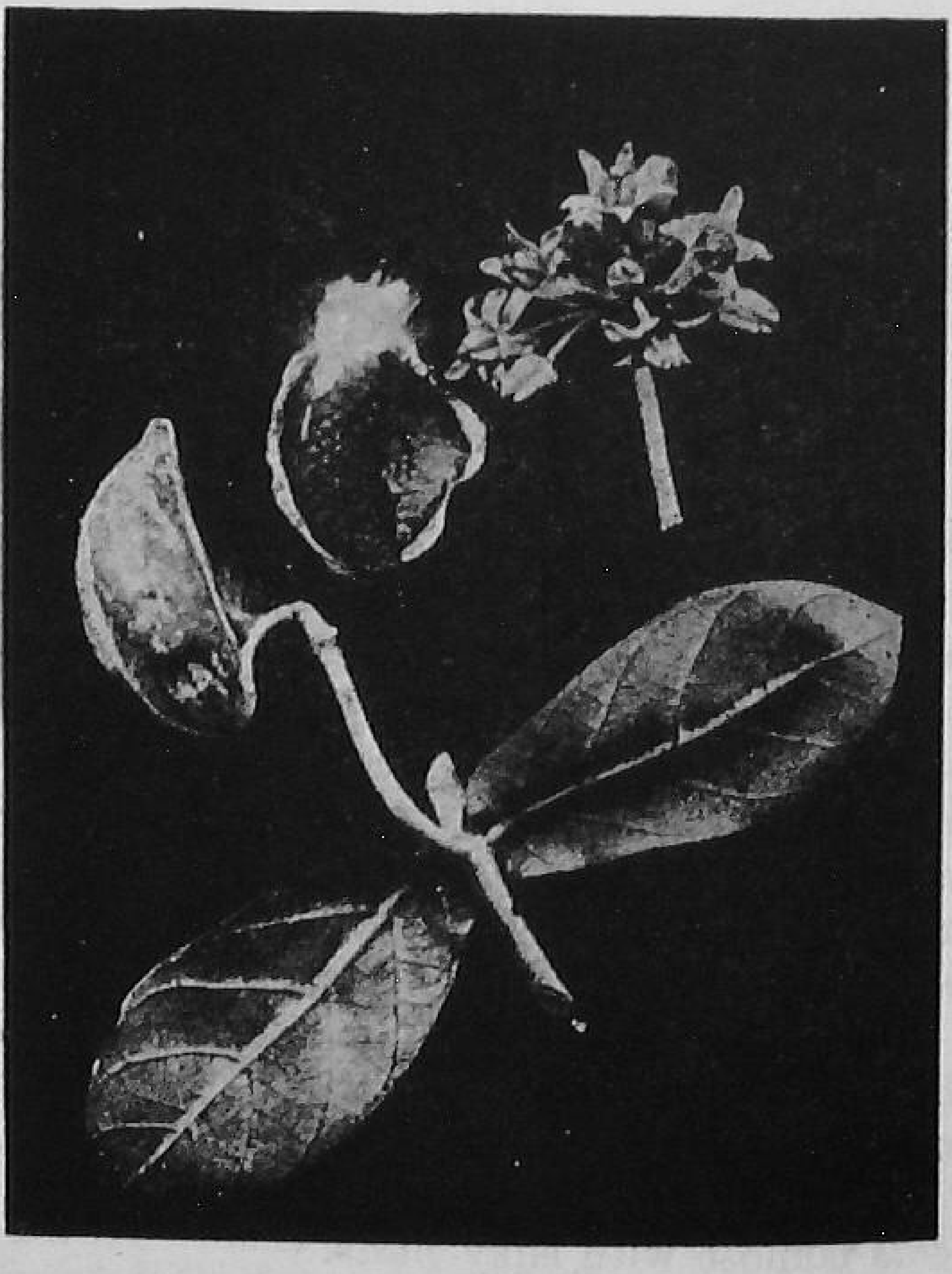

Fig. 381.—*Calotropis gigantea.* A branch, inflorescence and follicle.

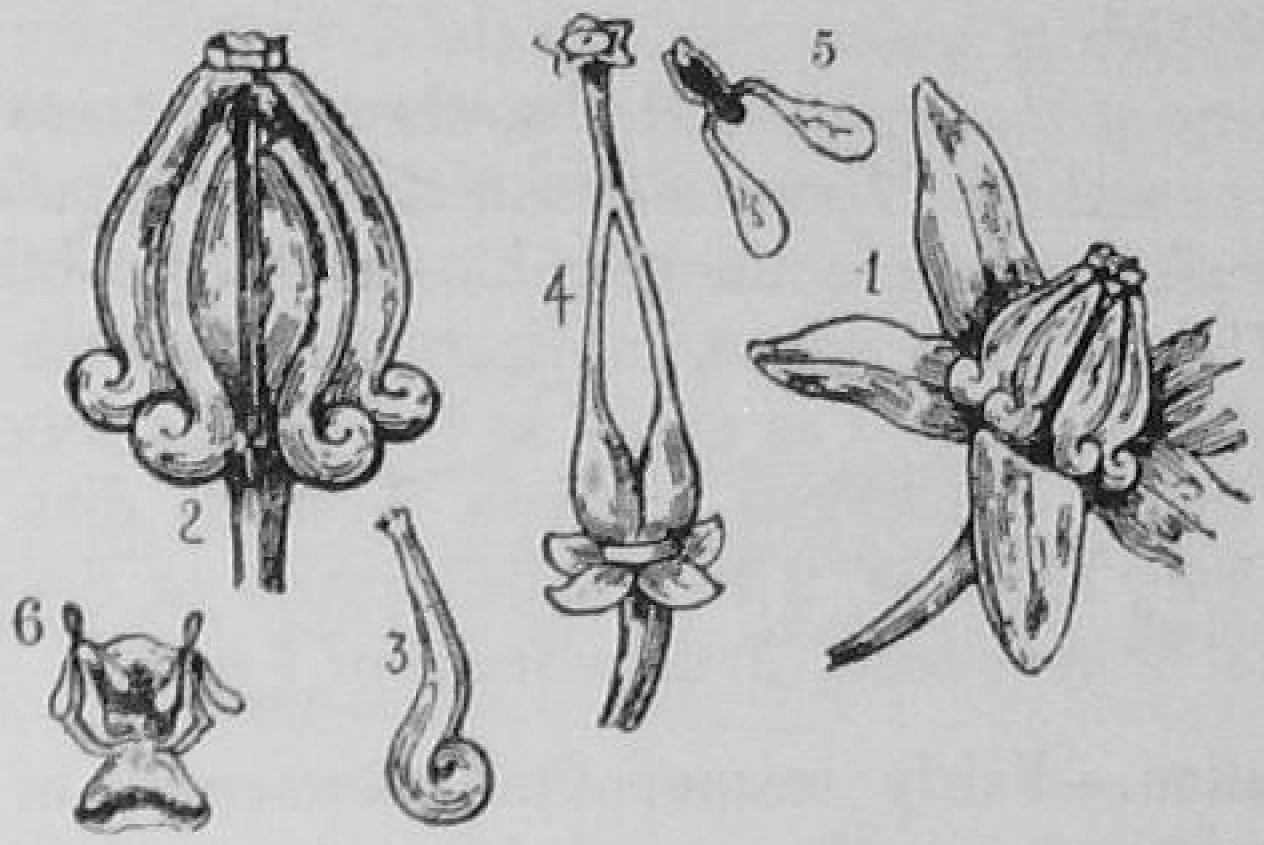

Fig. 382.—*Calotropis gigantea.* 1. a flower; 2. staminal column with corona; 3, corona; 4. postil; 5. pollinia, 6. stigma with pollinia.

Useful Plants.—

(1) *Calotropis gigantea*—green manure.
(2) *Hemidesmus indicus*—Indian sarasaparilla.
(3) *Ceropegia spp.*—ornamental.
(4) *Caralluma spp.*—ornamental.

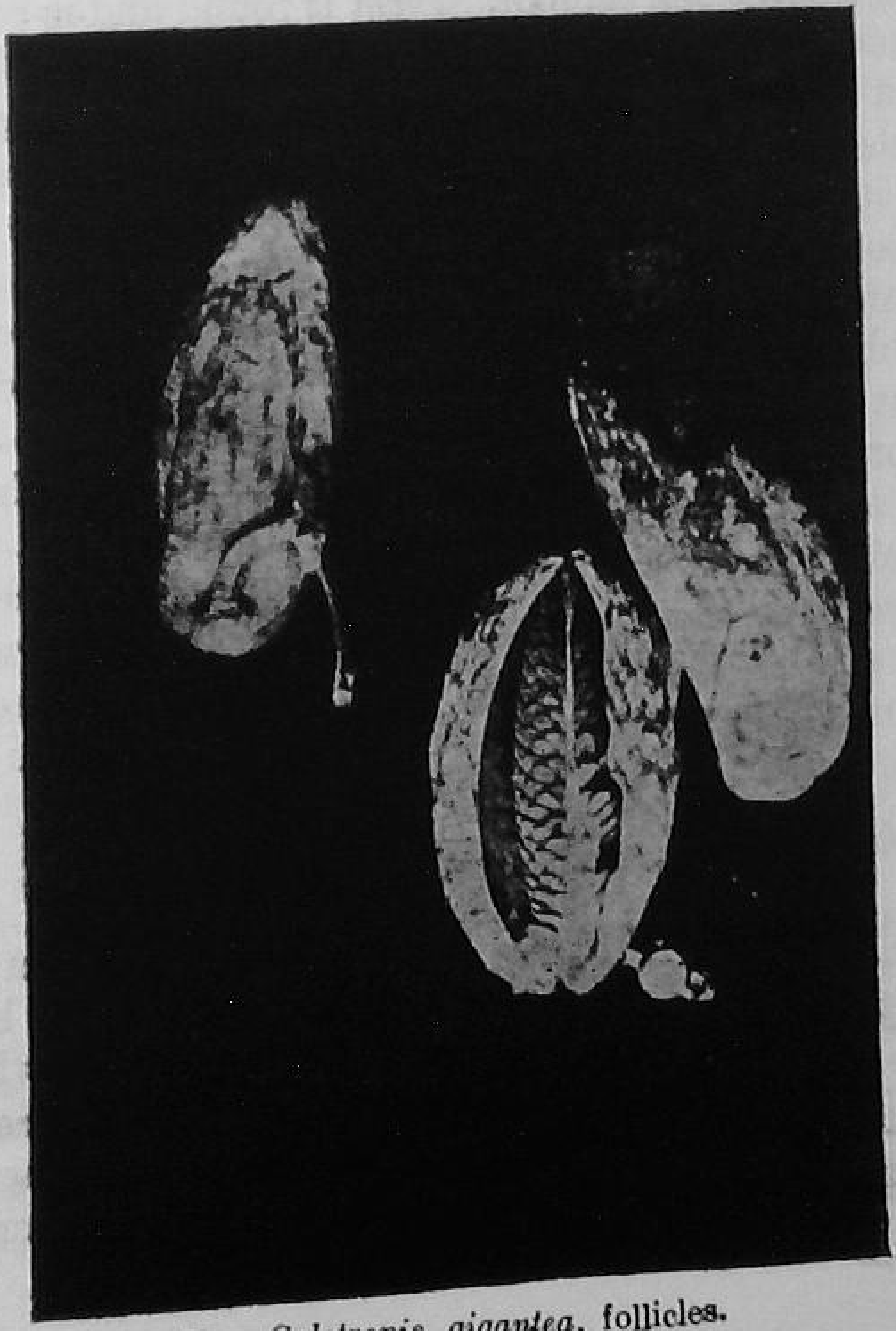

Fig. 383.—*Calotropis gigantea*, follicles.

29. Boraginaceae.

Characters of the family.—Herbs, shrubs or trees glabrous or often hispid or scabrid. *Leaves alternate* simple *exstipulate. Flowers* often in *scorpioid cymes*, actinomorphic or rarely oblique, hermaphrodite. *Calyx* gamosepalous, imbricate, *Corolla* with contorted or imbricate lobes. *Stamens* as many as the corolla lobes and alternate with them, epipetalous, *anthers* 2-celled, disk present or obsolete. *Ovary* superior, 2 to 4 celled entire or deeply 4 lobed. *Style* terminal or *gyno-basic*, *Fruit* a *drupe* or 4 *nutlets.*

Distribution.—Fairly cosmopolitan, numerous in the Meditterranean region.

TYPE :—*Trichodesma Indicum*, R. Br.

The plant is found growing in waste places and cultivated dry and irrigated fields. It is very common in black cotton soils. The plant is hardy and can withstand drought to some extent.

It is an erect diffusely branching hispid annual becoming perennial under favourable conditions. It attains a height of even 2 feet and has a thick taproot. *Stem* is round and is covered with simple and tubercle-based hairs. *Leaves* are simple, opposite below and alternate above, ex-stipulate, sessile, oblong-lanceolate and auricled at the base, margin of the leaf is entire and reflexed and both its surfaces are hairy. *Flowers* are solitary, axillary or leaf opposed on bent flower stalks. *Calyx* is hairy and deeply divided into 5 lobes which are hastate at the base. *Corolla* is white or light blue tubular below, the throat having reddish brown patches at the bases of the 5 triangular lobes which end in fine-twisted processes. *Stamens* are 5, attached to the corolla; filaments are very short; *anthers* cohere to form a cone. The back of anthers, and connectives are prolonged into finely pointed and twisted appendages. *Fruit* consists of a central 4-winged axis bearing 4 single-seeded nutlets which are polished grey with or without brown spots on the back. The inner surfaces of the nutlets are rough with cavities and ridges.

2. *Heliotropium curassavicum*, L.

A glaucous fleshy herb probably introduced from the West Indies, common on the Coromandel coast, on salt backwaters as at Madras, Vizagapatam and Tuticorin. The whole plant has a greyish or bluish green color, 4 to 10 inches. *Leaves* oblanceolate 1 to 2 inches long, *exstipulate* alternate. *Flowers* small, hermaphrodite in rather short pairs of unilateral spikes,

Calyx 5-lobed, *Corolla* 5-lobed white, yellow in the centre, *stamens* 5, epipetalous, no hairs or scales in the throat of the corolla. *Ovary* 2 carpelled, *style* distinctly swollen at base, when ripe the lobes of the ovary break apart, each containing one seed.

3. *H. ovalifolium*, Forsk.

A fairly common erect or decumbent, softly villous herb in waste lands and fallow fields, root stalk thick, *Flowers* in long slender ebracteate pairs of spikes, the calyx persistent after the nutlets fall. *Flowers* white.

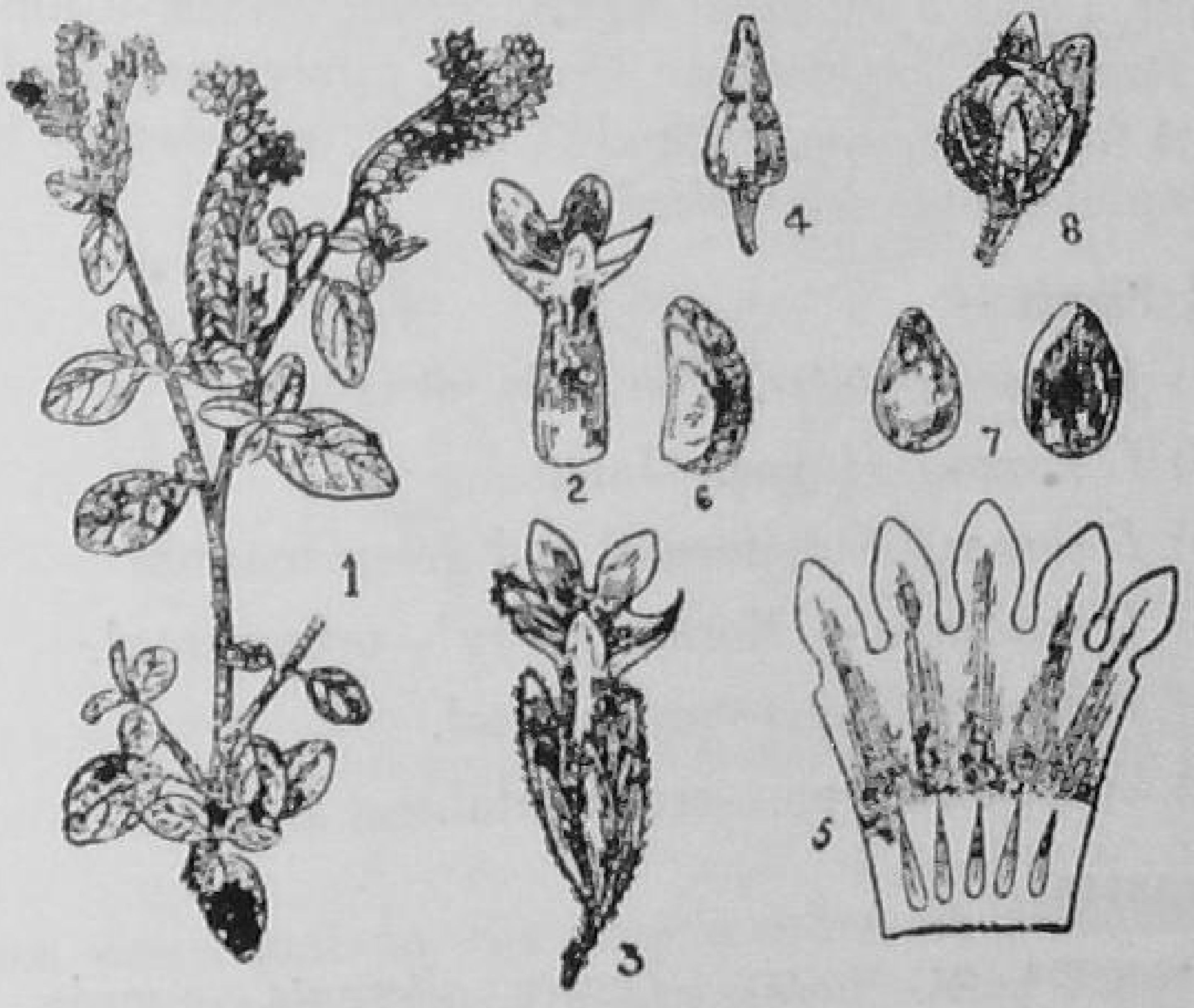

Fig. 384.—*Heliotropium ovalifolium*. 1. a branch; 2. corolla; 3. a flower; 4. an ovary; 5. corolla cut open; 6 and 7. nutlets; 8. a fruit.

Useful Plants.—

Cordia Myxa, L.—Sebasten tree.

Alkanna tinctoria Tausch—Alkanet root.

There are several garden plants.

30. Convolvulaceae.

Herbaceous or woody, mostly *climbing*, juice usually *milky*. *Leaves* alternate, simple, *stipules absent*. *Flowers* bi-sexual, actinomorphic, bracts often forming an involucre, sepals usually free, often imbricate, *persistent*. *Corolla* gamopetalous, showy, mostly funnel shaped, lobes 5, contorted, *stamens* 5, inserted towards the base of the corolla tube and alternate with the lobes, *anthers* 2 celled, longitudinal dehiscence. *Ovary* often surrounded by a disk, 1—4 celled. *Ovules* solitary or paired, erect, *style*

terminal. *Fruit* a capsule or fleshy and indehiscent, *seeds* with endosperm scanty and *folded or crumpled* cotyledons.

Distribution.—Cosmopolitan.

Evolvulus alsinoides L.—A very common perennial herbaceous weed, on open ground by roadsides and in other dry grassy places. The root stalk is woody and there are many spreading prostrate branches. The plant has a general silvery grey colour and the flowers intense blue. *Leaves* alternate, variable, lanceolate, oblong ovate or even sub-orbicular, *exstipulate*. *Flowers* small, blue, *Calyx* 5 subequal sepals, *corolla* rotate, 5 lobed limbs plicate ; *stamens* 5 epipetalous. *Ovary* 2, rarely one celled. *Styles* 2, distinct from the base, each cleft into 2, sub-clavate branches, *Fruit* a capsule, cotyledons *folded*.

Useful Plants.—

(1) *Ipomoea Batatas*, Poir.—Sweet potato.

(2) *I. Purga*. Hayne.—Jalap.

(3) *I. carnea*.—Ornamental and green manure

(4) *I. hederacea*.—'Morning glory'—ornamental.

(5) *Porana Volubilis*—ornamental.

(6) *Convolvulus spp.*—ornamental.

31. Solanaceae.

Herbaceous or woody. *Leaves alternate*, simple, *stipules absent*. *Flowers* hermaphrodite, mostly actinomorphic, *Calyx* 4—6 lobes, persistent, sometimes *accrescent*, *Corolla* gamopetalous usually 5-lobed, lobes folded, contorted or valvate, *stamens* 5, epipetalous, *anthers* 2 celled, opening lengthwise or by *apical pores*. *Ovary* 2 celled, the cells sometimes again divided by a false septum. *style* terminal, *Ovules* numerous, axile, *Fruit* a berry or capsule ; *seeds* with *copious endosperm* and *curved* or *annular embryo*.

Distribution.—Both in temperate and tropical regions.

Type :—*Solanum Melongena*, L.

This is the cultivated Brinjal plant. The plant is a shrub and is hairy and covered with stellate hairs, and also armed with prickles. *Leaves* alternate, exstipulate, petiolate, ovate, sinuate or lobed, covered with stellate hairs, and prickles on the veins, unequal at the base. *Flowers* in extra-axillary helicoid cymes, only one flower being perfect. The *calyx* is 5 lobed, stellately hairy outside, persistent and grows with the fruit, sometimes

prickly. *Corolla* violet, blue, rotate, 5 lobed (sometimes 6 to 8), stellately hairy outside, between the folds and on the plaits.

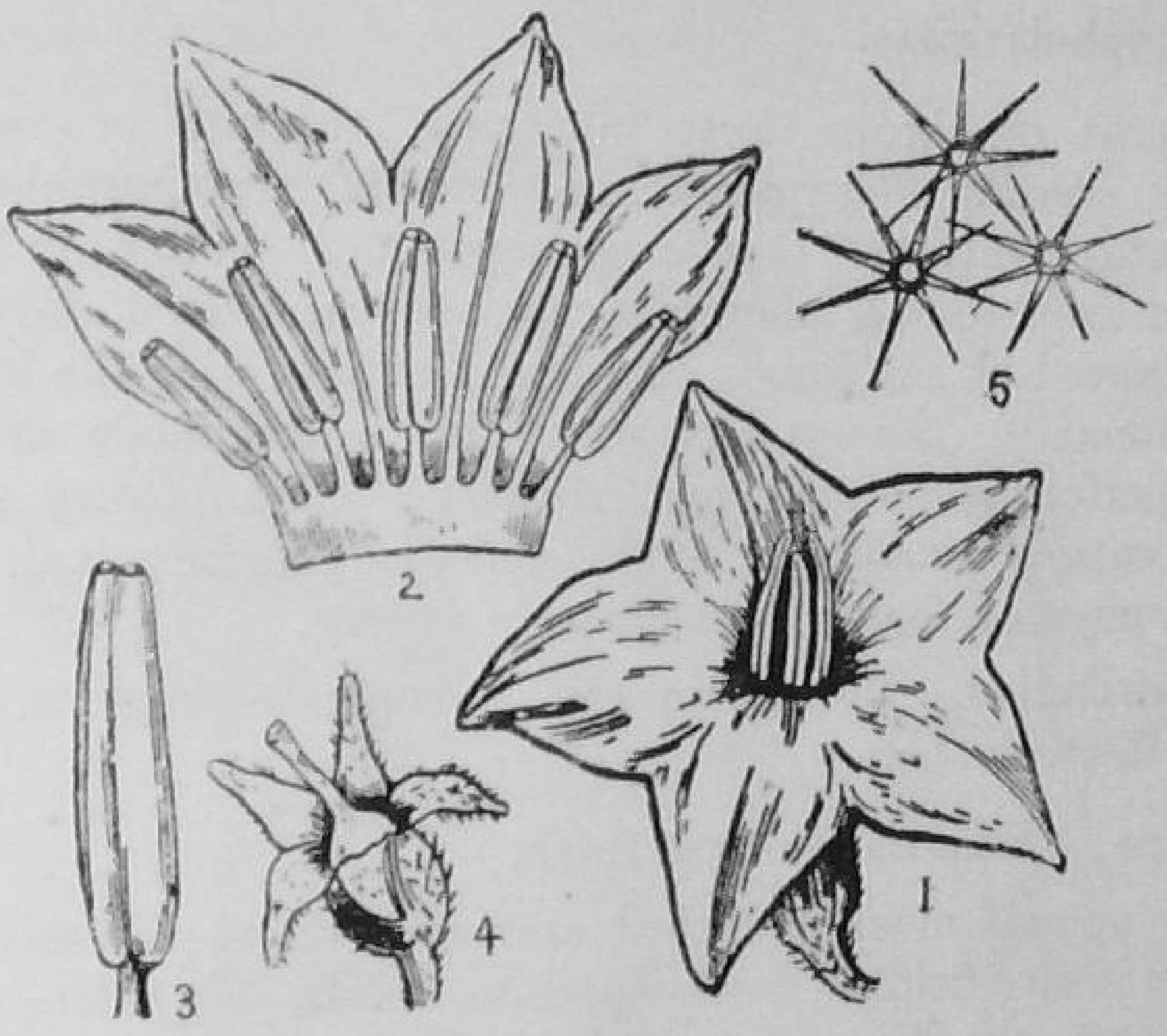

Fig. 385.—Floral parts of *Solanum Melongena*. 1. a flower; 2. corolla cut open; 3. a stamen; 4. calyx and pistil; 5. stellate hairs.

Stamens are equal to the corolla lobes, epipetalous; *filaments* short, and *anthers* open by *apical pores*. *Ovary* superior 2 celled and many-ovuled. *Fruit* is a 2 celled berry. *Seeds* flat compressed.

This plant exhibits a certain amount of variation in its flower under cultivation. On the same plant, we find corollas with lobes from 5 to 8, and as many stamens. The *fruits* also have many irregular cavities due to unequal growth and development of the placenta.

Useful Plants.—

(1) *Solanum tuberosum*—Potato.

(2) *S. Melongena*—Brinjal or egg plant.

(3) *Lycopersicum esculentum* Mill—Tomato.

(4) *Capsicum annum*, L.—Chillies or Capsicums.

(5) *C. frutescens*, L.—Chillies or Capsicums.

(6) *Nicotiana Tabacum* L.—Tobacco.

(7) *Atropa Belladonna*, L—Deadly nightshade.

(8) *Petunia spp*—Ornamental.

(9) *Cestrum spp.*—Ornamental.

(10) *Cyphomandra betacea*, Sendt.—Tree tomato.

32. Scrophularineae.

Herbs or shrubs, *leaves* alternate, opposite or verticillate *stipules absent*. *Flowers* bisexual, mostly zygomorphic. *Calyx* imbricate or valvate. *Corolla* gamopetalous, limb 4 to 5, often more or less 2-lipped, lobes imbricate, *stamens* often 4, didynamous or 2 inserted on the corolla tube and alternate with the lobes, the fifth (adaxial). *Stamen* represented by a staminode or absent, rarely perfect; *filaments* free. *Anthers* 2 celled. *Ovary* superior, sessile entire, usually perfectly 2-celled, *style* terminal. *Ovules* axile, numerous, *fruit* a *capsule*, rarely a berry.

Distribution.—Mostly in the temperate regions. Some also in the tropics.

Type :—*Stemodia Viscosa*, Roxb.

An annual much branched aromatic, viscid pubescent herb common in rice fields. *Leaves* opposite, sessile, *exstipulate*, more or less oblong, usually cordate and amplexicaul. *Flowers* axillary. solitary, bracteoles 1 or 2 small, violet. *Calyx* deeply 5 lobed, *Corolla* 2 lipped tube cylindric, often villous, thin, upper lip 2-lobed,

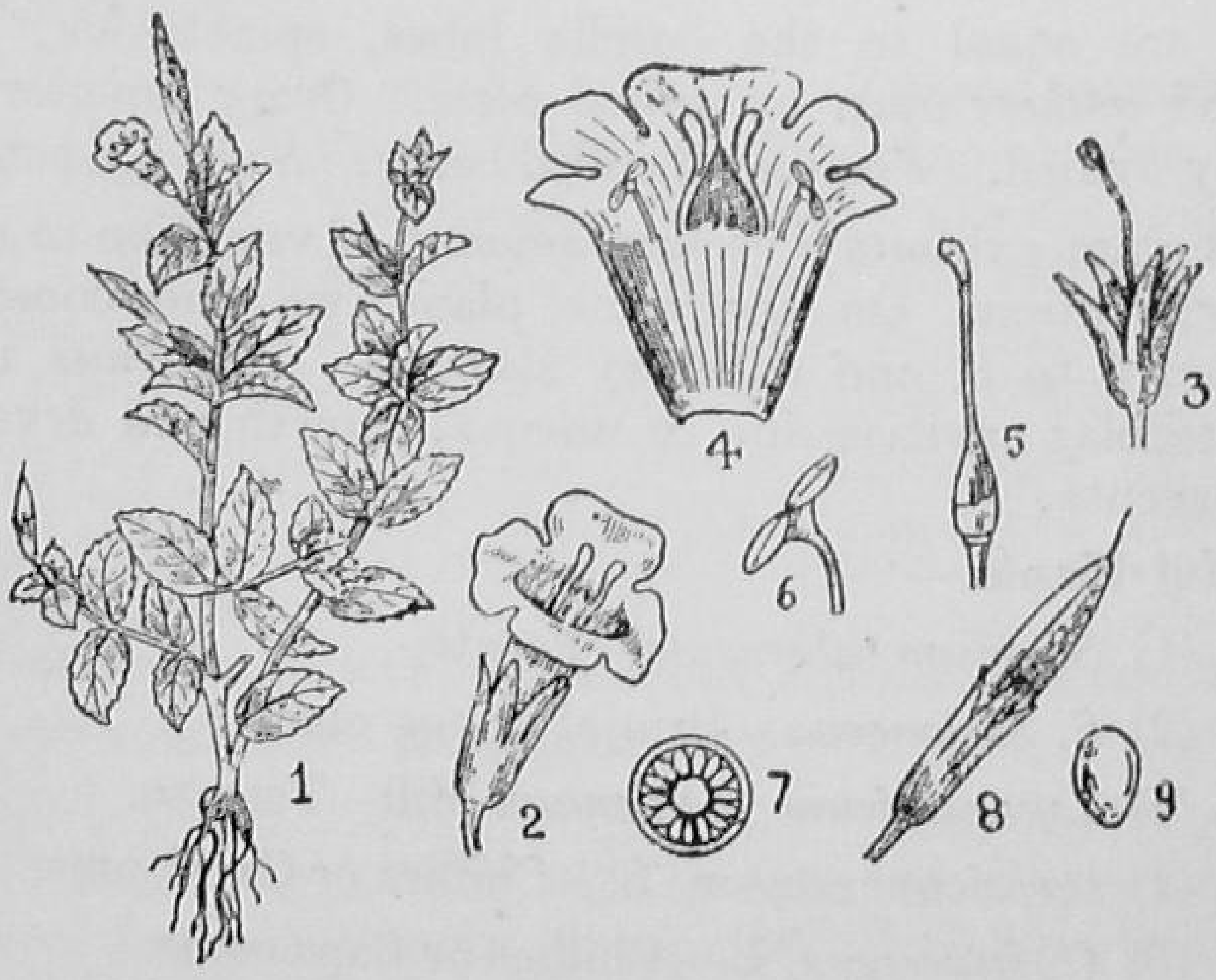

Fig. 386.—*Bonnaya veronicaefolia.* 1. a plant ; 2. a flower ; 3. calyx and pistil ; 4. corolla cut open ; 5. pistil ; 6. a stamen : 7. fruit cut across ; 8. a fruit ; 9, a seed.

lower 3-lobed spreading. *Stamens* 4, didynamous. *Ovary* many ovuled. *Style* filiform. Stigma 2 lobed. *Fruit* a globose or ovoid capsule. *Seeds* numerous, very minute.

Useful Plants.—

Digitalis purpurea L.—Foxglove; Many are of horticultural value.

Striga spp are root parasites.

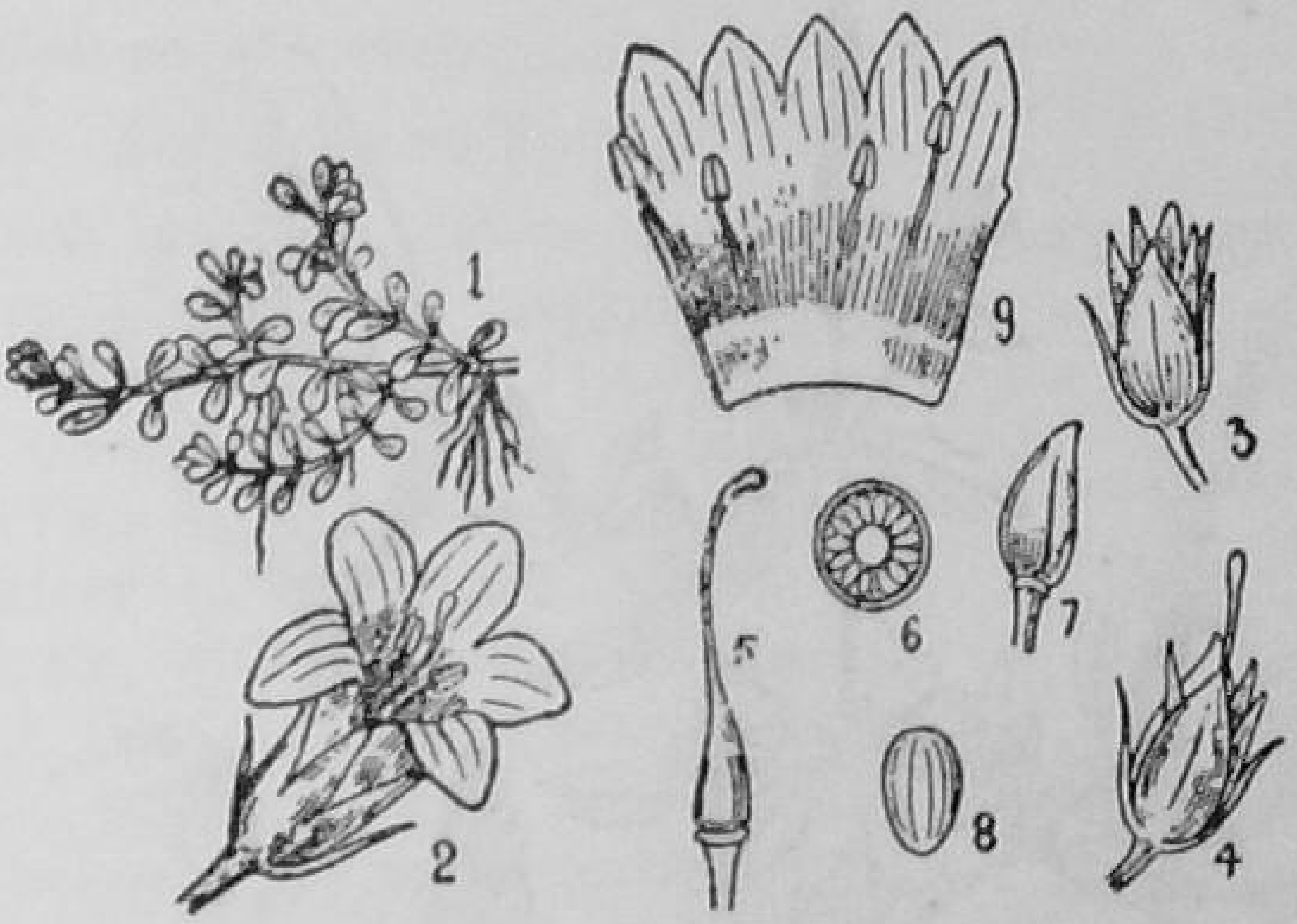

Fig. 387.—*Moniera cuneifolia*. 1. a branch; 2. a flower; 3. a flower bud; 4. calyx and pistil; 5. pistil; 6. fruit cut across; 7. a fruit; 8. a seed.

33. Acanthaceae.

Herbaceous or *climbing*, rarely shrubby. *Leaves opposite*, often with distinct *cystoliths*, *exstipulate*. *Flowers* hermaphrodite, zygomorphic; *bracts conspicuous*. *Calyx* segments or lobes 4–5 imbricate. *Corolla* gamopetalous 2-lipped, sometimes 1-lipped, lobes imbricate or contorted. *Stamens* 4, didynamous or 2 inserted on the corolla tube. Filaments free or partially connate in pairs, *Anthers* 2 celled or 1 celled by reduction, cells confluent or separated, sometimes one much smaller than the other, longitudinal dehiscence, disk present. *Ovary* superior, sessile on the disk, 2 celled. *Style* simple. *Ovules* 2 or more in each cell, axile. *Fruit* a *capsule*, mostly elastically dehiscent from the apex downwards, the valves removed and leaving the central axis, *funicles hard* and elastic forming the *retinacula*.

Distribution.—Warm parts of the world.

Type :—*Rungia repens*, Nees.

This is a much branched herb with slender glabrous branches. *Leaves* opposite, exstipulate, elliptic or elliptic lanceolate, shortly petioled. *Flowers* in one-sided spikes, with prominent bracts and bracteoles. *Bracts* have scarious margins. *Calyx* deeply lobed into 5 narrow lobes. *Corolla* 2 lipped with 2 epipetalous stamens. The *anther-lobes* are placed one above the other, and the lower lobe has an appendage. *The fruit* is a small compressed capsule. *Seeds* flat rounded.

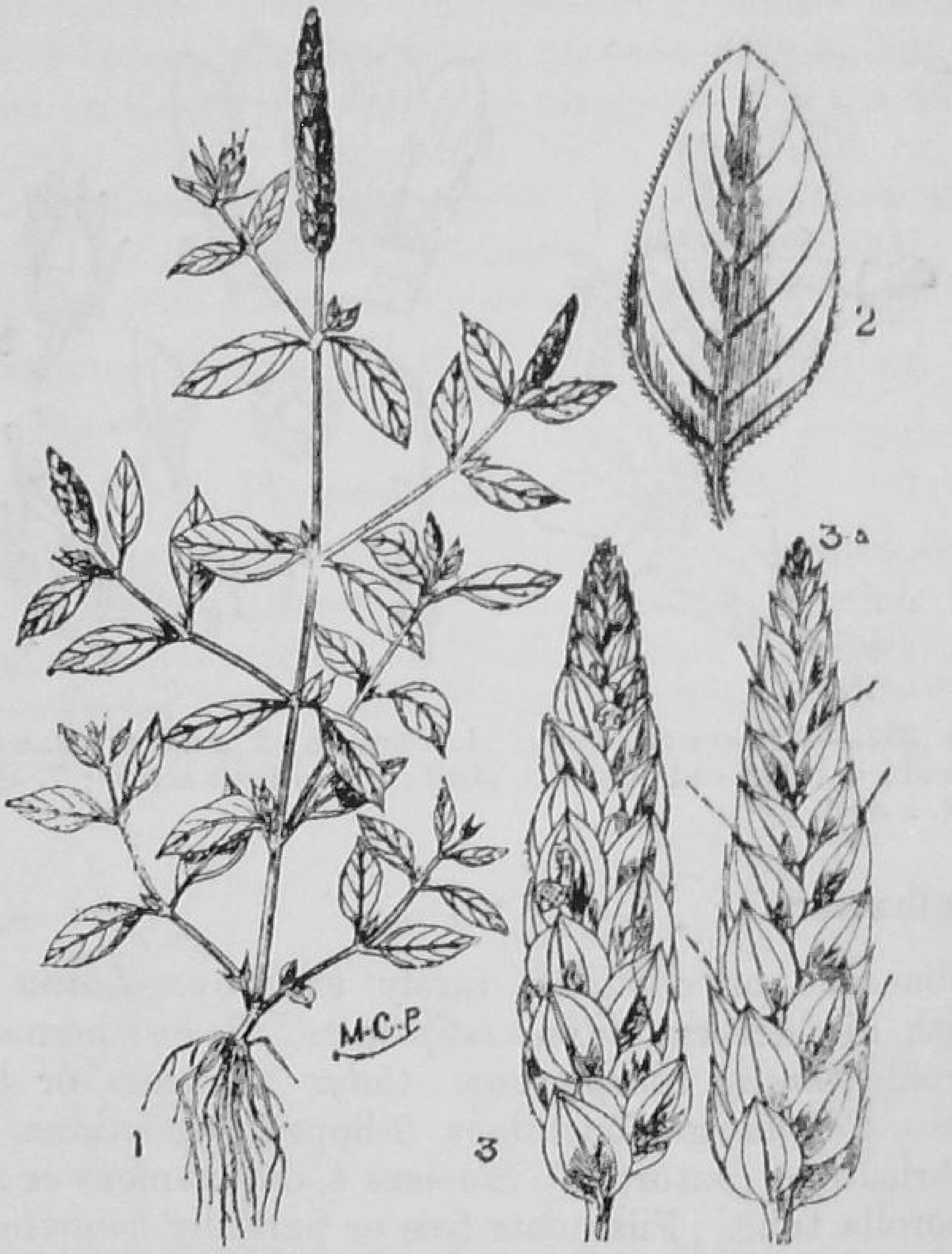

Fig. 388.—*Rungia repens*. 1. plant ; 2. leaf ; 3 and 3-a. spikes.

Useful Plants.—

Several are ornamental such as *Thunbergia* spp, *Strobilanthes* spp., *Eranthemum* spp, *Crossandra* spp., *Asystasia* spp., etc.

34. Labiatae.

Characteristics of the family.—Herbaceous, rarely woody, often *odoriferous* on account of essential *oil bearing glands ;* stems

usually *quadrangular ; leaves opposite* or whorled, simple ; *exstipulate ; Flowers* bisexual, Zygomorphic ; axillary or whorled in *verticillasters ; Calyx* persistent, of 5 sepals variously united, often 2-lipped ; *Corolla* gamopetalous, hypogynous, tubular ; 4—5 lobed, imbricate, often forming 2 lips or rarely 1 lip ; *Stamens*—epipetalous 2 or 4 ; *anthers* 2-celled; cells often *divergent*, opening lengthwise ; *Ovary* superior, of *2 deeply lobed carpels*, style *gynobasic ;* stigma bifid ; 4 ovuled, erect ; *Fruit* 4 *nutlets*, free or cohering in pairs ; *seed* without endosperm or scanty endosperm.

Distribution.—Cosmopolitan.

Types.—*Leucas aspera*, Spreng.

A much branched diffuse annual with square, hairy stems. *Leaves* opposite, simple, exstipulate, sessile or shortly stalked, linear, coarsely crenate, and hairy on both the surfaces. *Flowers* sessile, in verticillasters in the axils. *Bracts* linear, acute, with long hairs on the margins. *Calyx* is monosepalous, persistent, tubular, bent and constricted below ; the upper portion of the tube is ribbed and hairy, but the lower half is glabrous and membranous; the mouth of the tube is oblique, with the small upper teeth projecting above. *Corolla* white, labiate ; upper lip narrow, densely hairy outside, lower lip broad, flat, three-lobed, the middle lobe being the largest, obovate and the lateral smaller. *Stamens* are epipetalous, didymous and included within the upper lip ; anthers red. *Ovary* is superior, deeply four-lobed and is surrounded by a lobed disk. The style is long and gynobasic. *Fruit* of four oblong nutlets, rounded at the back and angled inside.

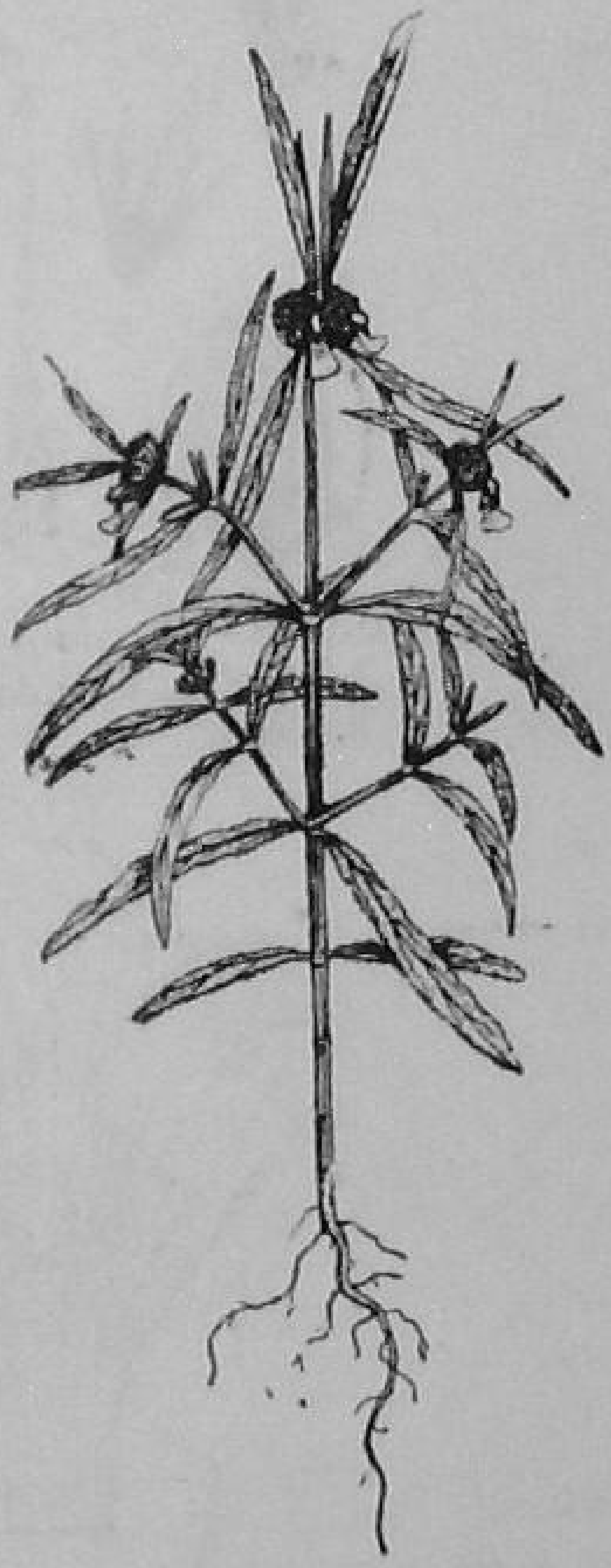

Fig. 391—A branch of *Leucas aspera*.

Useful Plants.—

(1) *Mentha viridis*—Mint.
(2) ,, *piperita*—Peppermint.
(3) *Lavendula vera*—Lavender.
(4) *Pogostemon Heyneanus*—Patchouli.

(5) *Origanum Marjorana*—Marjoram.
(6) *Thymus vulgaris*—Thyme.
(7) *Ocimum sanctum*—'Tulsi'.
(8) *Coleus Parviflora*—Root vegetable.
(9) *C. aromaticus*—Medicinal.
(10) *C. Vettiveroides*—Roots scented.

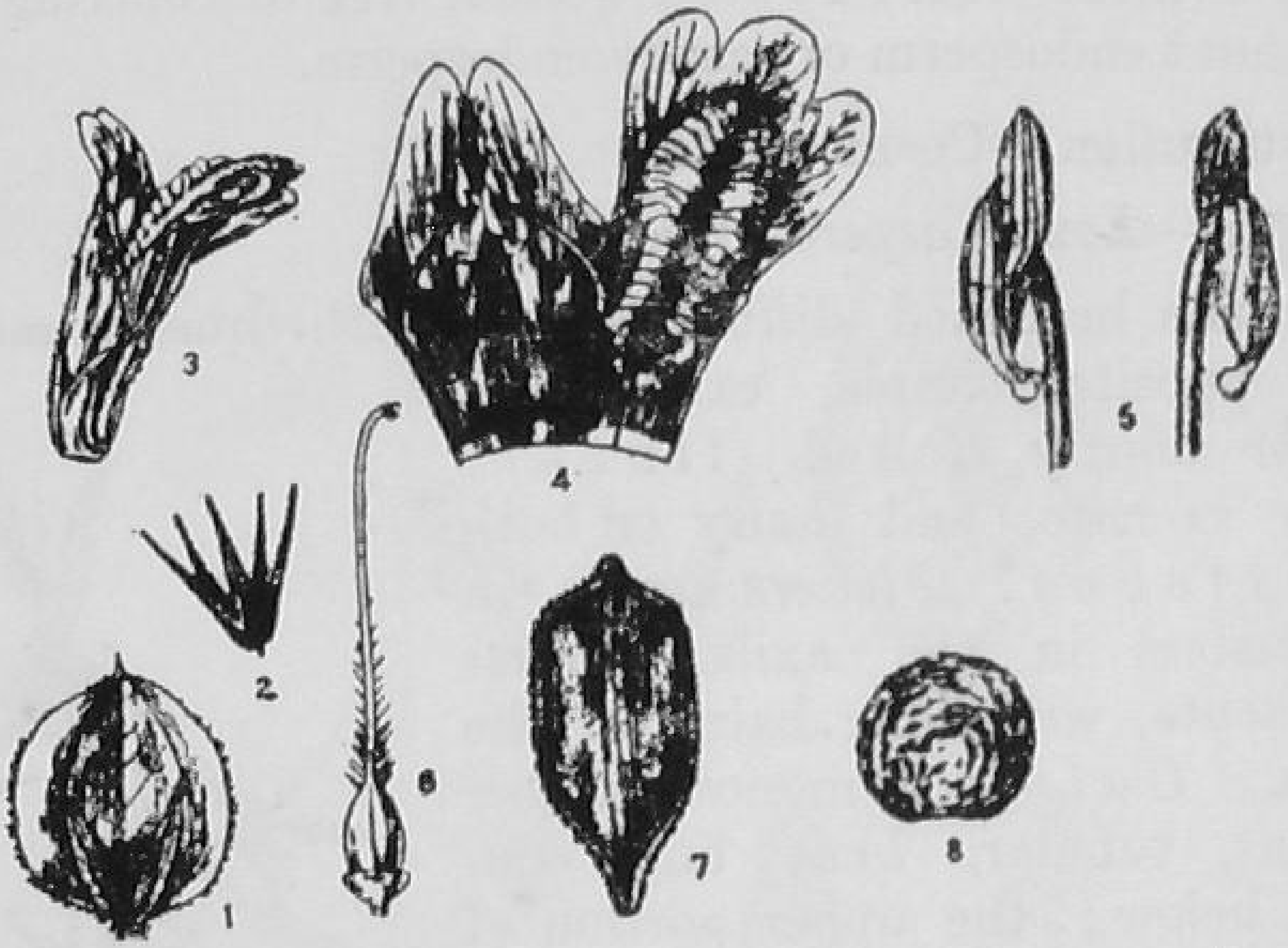

Fig. 389.—*Rungia repens.* 1. bract and bracteoles ; 2. calyx ; 3. corolla ; 4. corolla laid open ; 5. stamens ; 6. ovary ; 7. fruit ; 8. seed.

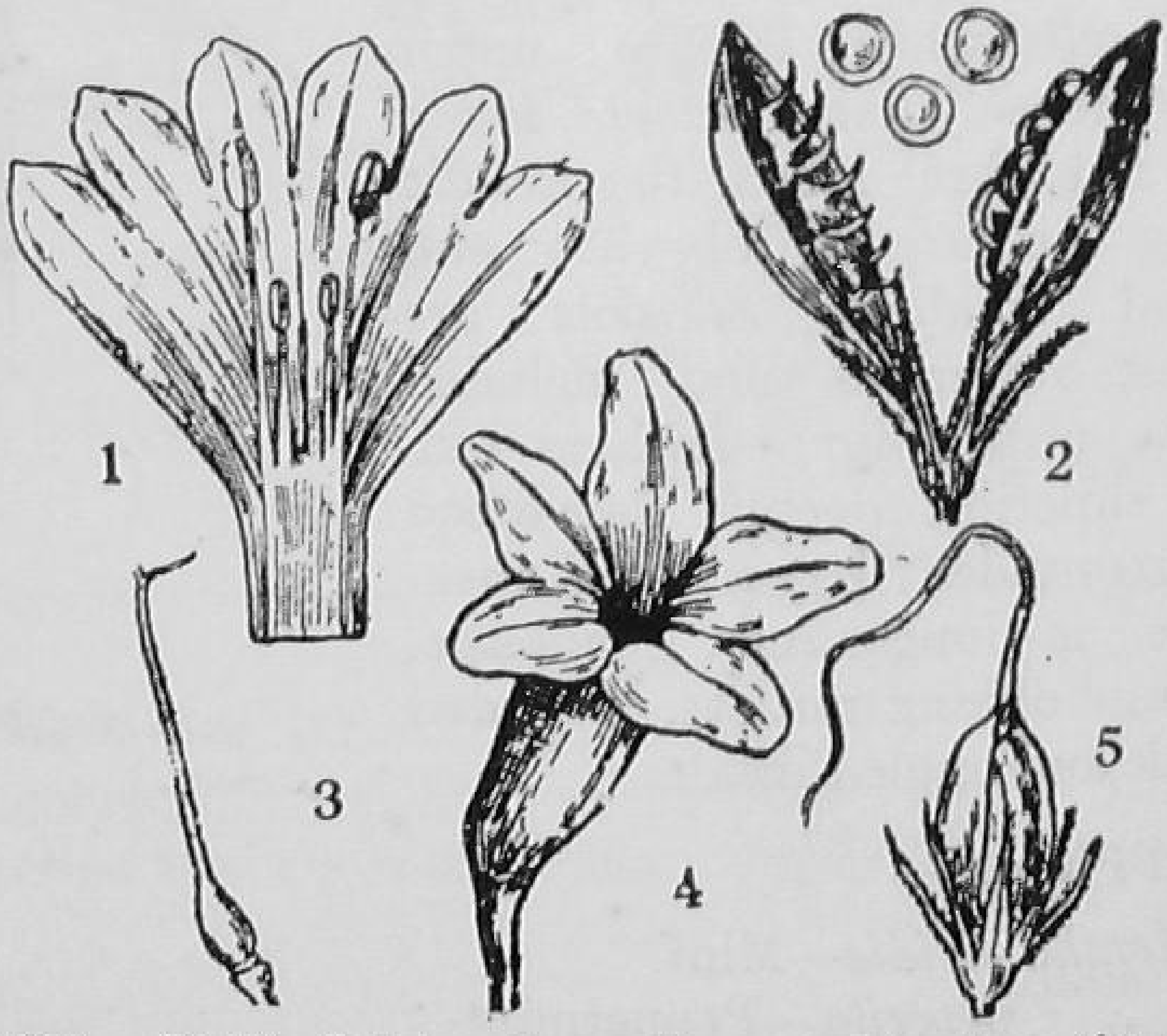

Fig. 390.—*Ruellia Patula.* 1. corolla opened to show the stamens ; 2. fruit burst open showing the retinacula and seeds ; 3. pistil ; 4. corolla ; 5. fruit.

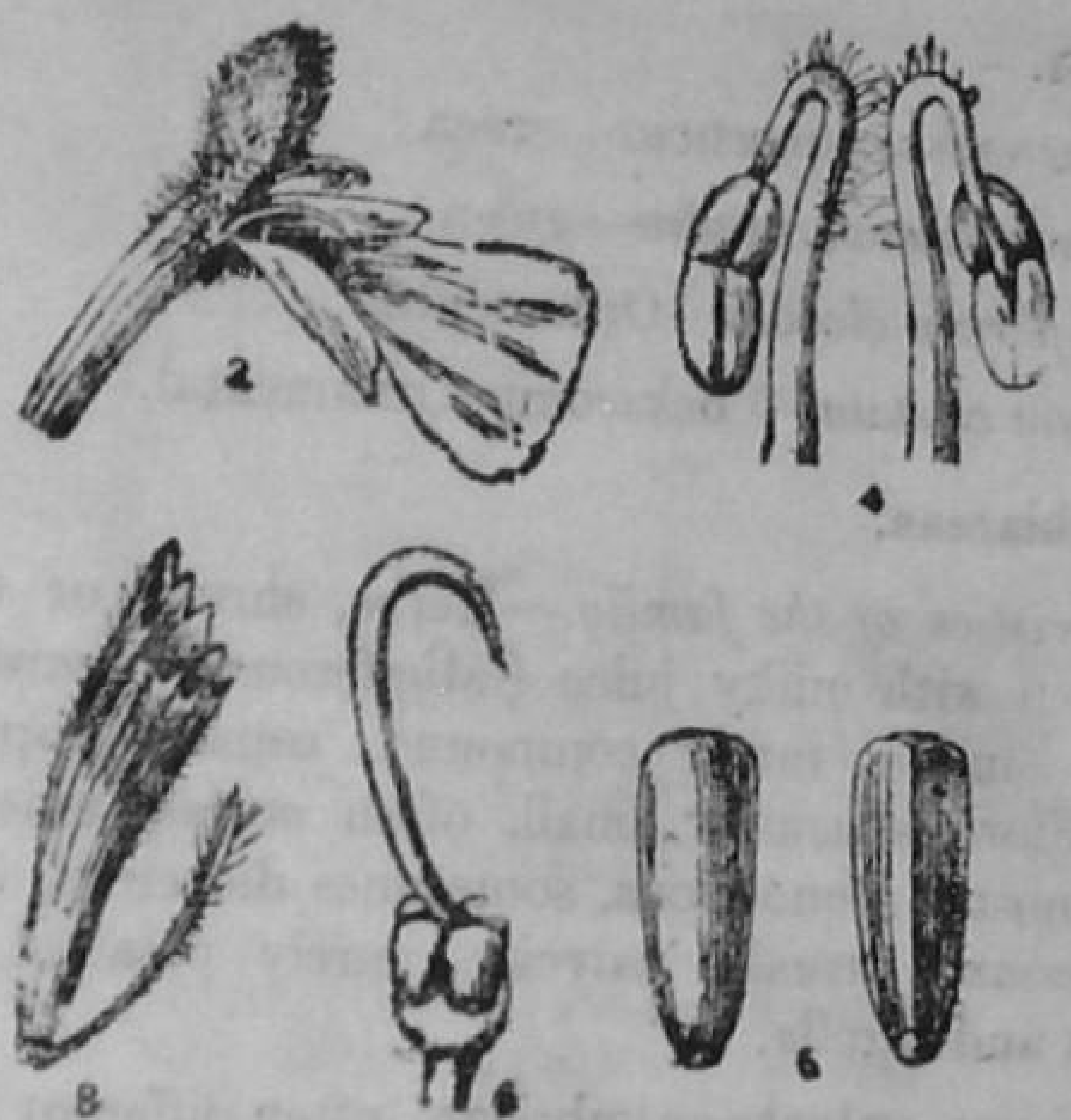

Fig. 392.—*Leucas aspera*. 2. corolla; 3. calyx and bract; 4. stamens; 5. pistil; 6. nutlets.

35. Amarantaceae.

Characteristics of the family.—Annual or perennial herbs, rarely undershrubs or climbers; *Leaves* alternate or opposite; simple *exstipulate; Flowers* actinomorphic, usually bisexual, small; in *spikes* or *heads* with often scarious bracts and bracteoles, the latter sometimes hooked; *Perianth* of 3—5 sepaloid parts, free or nearly so; imbricate, more or less dry and membranous; petals absent; *stamens* mostly five *opposite the sepals*, hypogynous; *filaments* united at the base into a short tube, often with staminodes between; *Ovary* superior 1-celled; *style* short or long; *stigma* capitate or 2–3 fid; *ovules* solitary or rarely several, on a basal funicle; *fruit* a membranous utricle or opening by a lid; *Seeds* globose, compressed or ellipsoid, smooth, endospermous.

Distribution.—All over the world.

Type:—*Achyranthes aspera*, L.

This plant produces a few straggling branches and the stem is rounded and striate. *Leaves* simple, exstipulate, opposite, petioled shortly rotund or obovate, wavy margin, and hairy on both surfaces. *Flowers* in terminal spikes, stiffly deflexed and crowded. *Bract* and *bracteoles* spinescent at their tips, persistent. The *perianth* consists of 5 ovate-oblong, or lanceolate, shining, glabrous sepals with spinescent apex and membranous margins. These become hardened and persist with the fruit. *Stamens* 5, alternating with 5, truncate, fimbriate staminodes. *Fruit* indehiscent with a membranous hardened pericarp. *Seed* cylindric.

Useful Plants.—

(1) *Amarnnthus gangeticus*—green :

(2) *Alternanthera triandra*—green :

(3) *Gomphrena globosa*—Ornamental :

(4) *Celosia cristata*—Cockscomb Ornamental.

36. Euphorbiaceae.

Characteristics of the family.—Herbs, shrubs or trees, rarely climbers, often with milky juice (laticiferous) ; *Leaves*—alternate or opposite, simple, rarely compound, usually stipulate, often glandular. Flowers usually small, often *minute* unisexual, male and female mostly monoecious, sometimes dioecious, inflorescence variable. *Perianth* usually calycine, rarely petaloid, sometimes of both calyx and corolla.

Calyx inferior, valvate or imbricate, often different in the sexes. *Corolla* when present free, sometimes united (Jatropha) : *Stamens* from 1 to 1000 free or connate ; *anthers* 2-celled ; rudimentary ovary often present in the male flowers ; *ovary* mostly 3-celled ; *styles* free or united at the base ; *Ovule* solitary or paired. *Disc* often present in both sexes, annular or of separate glands. *Fruit* a capsule or drupe, *seeds* often with a conspicuous *caruncle ; endosperm* mostly copious.

Distribution.—Tropics and temperate regions.

Type :—*Phyllanthus maderaspatensis*, L.

Euphorbia thymifolia, L.

Ricinus communis,

Phyllanthus maderaspatensis, L., is a free, branching annual, the youngest branches simulating pinnate leaves. *Leaves* small, alternate, bifarious, shortly petioled with lanceolate, peltate stipules, obovate-cuneate, truncate or rounded at the apex, often mucronate, the nerves being conspicuous on the lower surface of the leaf. *Flowers* unisexual, monæcious ; male flowers very small, sessile and clustered in the axils ; female flowers are larger, solitary, stalked. *Sepals* in both the flowers 6, obovate with white margins. *Stamens* 3, filaments united. *Ovary* superior, 4 celled, with 2 ovules in each. *Fruit* is a capsule with 3 lobes. *Seeds* trigonous, and dorsally rounded.

Euphorbia thymifolia, L., is a creeping small plant abounding in milky juice. *Leaves* small, opposite, exstipulate with small stipules. *Flowers* unisexual, monœcious and collected together into inflorescences simulating single flowers, called *cyathia*. A *cyathium*

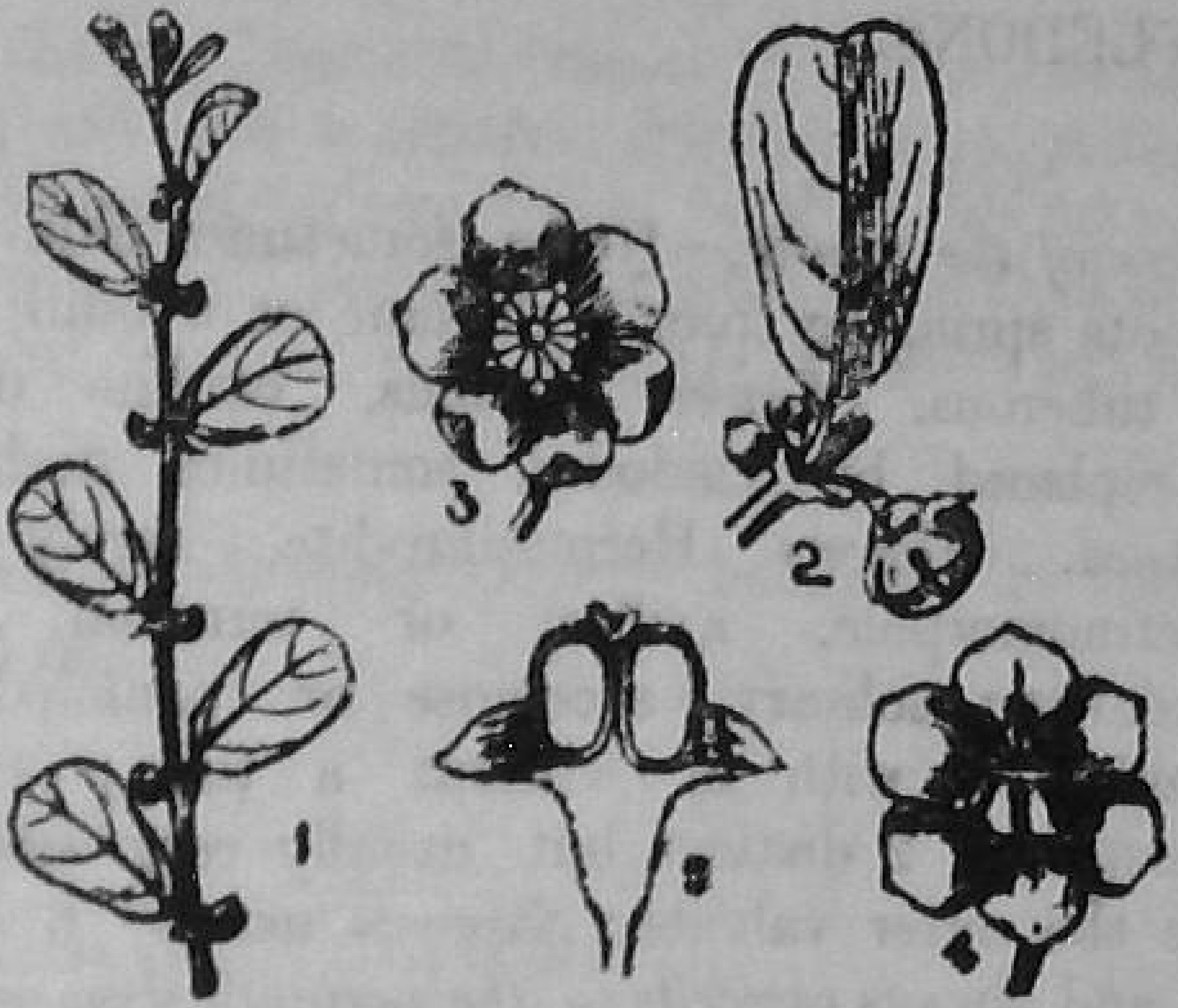

Fig. 393.—*Phyllanthus maderaspatensis.*
1. a branch ; 2. a leaf and two flowers ;
3. male flower ; 4. a female flower ;
5. fruit cut through.

consists of a 5-lobed tubular involucre enclosing a solitary stalked ovary and a number of stamens. The *ovary* represents a female flower and each stamen is a male flower. Between the limbs of the involucre there is a gland. *Fruit* is a hairy capsule having 3 cavities and 1 trigonous seed in each.

Ricinus Communis, *L.*—The Castor is a familiar oil-seed crop, cultivated and run wild. The plant is a shrub annual or perennial ; *Leaves* simple, alternate, with long petioles, lobed palmately (7-9), palmate veined ; *Flowers* in terminal panicles, monoecious, upper generally male and lower female. Apetalous ; *Male Calyx* membranous, 3-5-segments ; *Stamens* numerous, united into several bundles (*polyadelphous*); *anther* lobes divergent ; *Female calyx.* Gamosepalous, caducous, carpels 3 united, ovary 3 lobed, 3 celled with a single ovule in each cell. *Styles* 3 each with a bifid stigma ; *Fruit* Dry, breaking into 3 cocci, seed albuminous, one in each coccus.

Useful Plants.—

(1) *Hevea brasiliensis*—Para or Hevea rubber.
(2) *Manihot Glaziovii*—Ceara rubber.
(3) *Manihot utilissima*—Tapioca, Cassava.
(4) *Ricinus communis*—Castor oil.
(5) *Codiaeum species*—Garden crotons.
(6) *Emblica officinalis*—Hindi, Amla ; Tam. Nelli.
(7) *Cicca distycha*—Tam. Arunelli.
(8) *Aleurites species*—Tung oil.
(9) *Mallotus philippinensis*—Kamela orange dye.
(10) *Euphorbia pulcherrima*—the Poinsettia—Ornamental.

MONOCOTYLEDONS.

1. Liliaceae.

Characters of the family.—Herbs, sometimes climbing, mostly perennial, roots springing from a rhizome or a bulb or a corm; sometimes tuberous. *Leaves.* Various, cauline or radical; sometimes replaced by cladodes, sometimes fleshy, *usually parallel veined. Flowers* Hermaphrodite, rarely unisexual, regular, actinomorphic, axillary or terminal, sometimes large and showy; solitary, racemose or panicled. *Perianth* mostly *corolla-like* with or without a tube; segments or lobes 6; mostly in 2 distinct but usually *very similar series*, imbricate or the outer valvate; *Stamens* usually 6 hypogynous or adnate to and always *opposite to the perianth-segments; Anthers* 2 celled; dehiscing longitudinally; *Ovary superior* 3 celled; axile placentation; style entire or divided; *Ovules* usually numerous; *Fruit* a loculicidal or septicidal capsule or a fleshy berry; *Seed* endospermous.

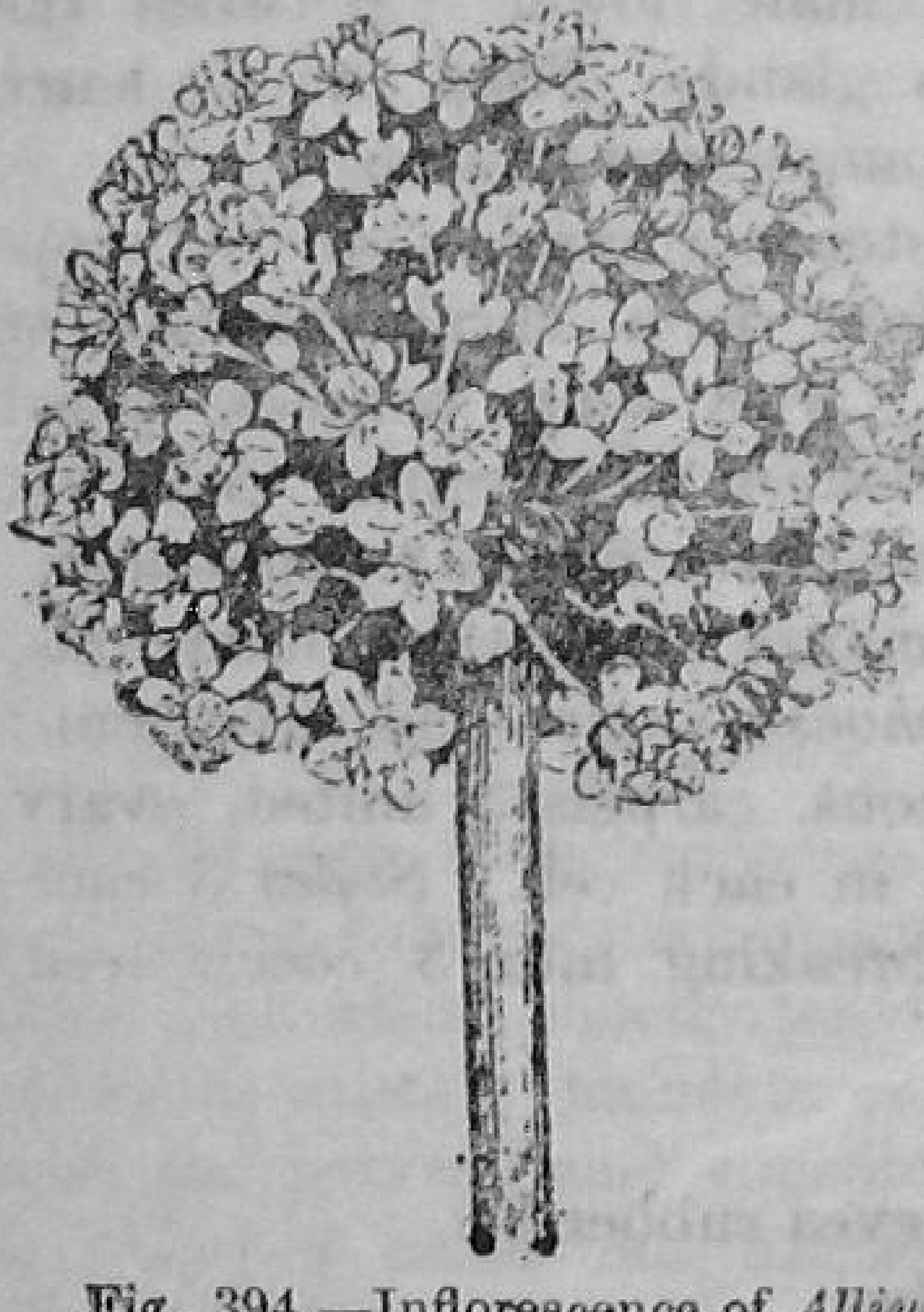

Fig. 394.—Inflorescence of *Allium cepa.*

Fig. 395.—A plant of *Gloriosa superba* with its stem-tuber.

Type:—*Gloriosa superba, L.*

This is a very common climbing plant with large, scarlet, very showy flowers. This plant possesses underground stem-tubers, which have the shape of a country plough (hence the Tamil name *Kalapaikizhangu* of this plant), and the aerial branches

arise from them. *Leaves* alternate, sessile, Lanceolate with the apex drawn out into a tendril. *Flowers* large, solitary, axillary. *Perianth* of 6 lobes, in two series, petaloid, scarlet; lobes linear-lanceolate with wavy margins and reflexed, instead of being erect. *Ovary* superior, 3 celled, with the style turned to one side. *Fruit* a capsule.

Distribution.—Cosmopolitan, abundant in temperate and sub-tropical regions.

Useful Plants.—

(1) *Allium Cepa*—The onion.

(2) *Allium Sativum*—The garlic.

(3) *Colchicum antumnale*—Colchicine plant.

(4) *Asparagus officinalis*—edible.

(5) *Yucca gloriosa*—Adam's Needle, fibre for carpets, etc.

(6) *Alœ vera*—medicinal.

2. Musaceae.

Perennial herbs, with a rhizomiferous stem; the apparent stem is formed by the imbricate bases of the petioles, erect, usually tall. *Leaves spirally arranged*, very large; midrib thick; veins pinnately parallel and numerous extending to the margin. *Flowers* mostly unisexual; clustered and subtended by large green *Spathaceous* bracts, the male within the upper bracts, the female within the lower bracts, zygomorphic. *Perianth* outer and inner usually both petaloid, free or variously united. *Stamens* 5, perfect with a rudimentary small sixth one; filaments filiform; *Anthers* 2 celled, the cells parallel and contiguous; *Ovary* inferior 3-celled—each cell with numerous ovules on an axile placenta; *Style* filiform with a lobulate stigma; *Fruit fleshy* berry; 3 celled. *Seeds* with a hard testa and copious endosperm.

Distribution.—Tropics of the world.

Musa paradisiaca, L. the Banana may be considered as a type. In this plant flowers are in a fleshy spike which rises from the underground stem. The lower flowers are female, the middle ones bisexual and the upper male. The bracts are large, leathery and spathaceous. The calyx is tubular, slit down on one side.

The corolla is reduced to a single membranous petal on the posterior side, the running as two teeth united with the Sepals in the anterior side and 5 Labiate. The *ovary* is *inferior*, 3-celled with many ovules, placentation axile ; *Fruit* a berry.

Useful Plants.—

(1) *Musa paradisiaca*—The Banana or the plantain.

(2) *M. textilis*—Manilla Hemp for fibre.

(3) *M. cavendishii*—Canary banana.

3. Palmae.

Characteristics of the family.—Plants are erect, woody, or arborescent, trailing or climbing plants, usually with a simple *unbranched* stem ; stem often covered by the *persistent bases of the leaves.* Tap-root soon disappearing and replaced by *roots from the base of the stem ; Leaves* scattered in the climbing species and in others in a *terminal cluster*, sometimes very large, entire, *pinnately* or *digitatedly* divided, the leaflets folded induplicately or reduplicately in bud, often sharp at the apex and prickly on the margins or mid-rib ; rachis often expanded at *the base into a fibrous sheath ; Flowers* small, actinomorphic, hermaphrodite, monœcious or dioecious, sometimes polygamous arranged in an often paniculate inflorescence—a *Spadix* enclosed in one or many valved spathe ; the flowers being amongst or below the leaves ; *spathes* leathery or membraneous, bracteoles often connate below the flowers ; *Perianth* double. *Sepals* 3 separate or connate, imbricate or open in bud. *Petals* 3, separate or connate, usually *valvate* in the *male* flowers and imbricate in the *female ; Stamens* usually 6, in two series, rarely numerous ; *anthers* 2 celled ; *Ovary* superior, rudimentary or absent in the male flowers ; 1—3 *celled*, or carpels 3 and distinct or connate only at the base ; *ovule* solitary and erect or pendulous from the inner angle of each carpel or cell of the ovary. *Fruit.* Berry or Drupe, 1—2 celled or fruiting carpels separate or distinct ; mesocarp often fibrous ; *seed endospermous*, endosperm sometimes *ruminate ; embroy small.*

Distribution.—It is mainly distributed in the tropics of both the new and the old world and constitutes one of the most striking features in the vegetation of these parts. Plants are either solitary or gregarious and often seen by the banks of rivers or in dense tropical forests.

Type 1. *Cocos nucifera*, L. The Coconut Palm

This is a tall tree with a straight, unbranched stem, thickened at the base, annulate, varying in height from fifty to eighty feet. *Leaves* are very large with a very long petiole expanded at the base where it clasps the stem, pinnately compound; leaflets are equidistant, linear, coriaceous. *Flowers*, unisexual, monoecious, in a branched spike, enclosed by a large spathe. *Female flowers*, few, large, towards the basal portions of the branches of the spike, and sometimes with a male flower on each side; there are two broad bracteoles. *Perianth* of 3 sepals and 3 petals, all accrescent. *Ovary* superior, 3 celled. Male flowers of 3 very short sepals and 3 oblong petals, both valvate. There are 6 stamens. *Pistillode* present or not. The *fruit* a fibrous drupe, with a single massive seed, which consists of a huge mass of endosperm enclosing a cavity filled with a liquid (coconut milk) and a small embryo embedded in the endosperm.

Type 2.—*Borassus flabellifer*, *Linn.* (*B. flabelliformis*, *Linn.*) The Palmyra Palm.

This familiar palm, a native of Tropical Africa, is common all over India and in almost all the districts in Madras Province, excepting in the higher elevations. It grows wild (self-sown) or cultivated and from sea-level up to 2,500 ft. *Stem* grows up to 100 ft. high and 3 ft. in dia. near the ground with a dense mass of long rootlets. The greyish black stem is swollen above the middle and again contracted above; when young clothed with the dry leaves or the bases of petioles; old stems marked with the black narrow scars of the petioles. *Leaves* 2 to 5 ft., the margins split into 60—80 linear lanceolate, acuminate, segments with spinulose margins, petioles 2 to 4 feet long, stout, semiterete, the edges armed with hard, horny, spinescent serratures; *Flowers*, unisexual and dioecious. *Spadix* simply branched, sheathed with numerous open spathes, male spikes 1—3 at the ends of branches, cylindric, densely clothed with thick closely imbricating bracts, numerous minute unilateral spikelets concealed by these bracts so as to appear immersed in the spike, the flowers coming to the surface one by one as they successively open; *stamens* 6, filaments *connate with the corolla* into a stalk; female spikes terminating the branches of spadix; *flowers* globose, one inch dia., *sepals* 3, imbricate, *petals* 3 convolute; *Ovary* superior 3—4 celled. *Fruit*, Subglobose 6 in. dia., enclosed by the enlarged and partly fleshy perianth.

Pyrenes.—1 to 3, Obcordate, fibrous outside, endosperm horny.

Useful Plants.—Perhaps there is no family whose members are so useful to man barring Gramineae and Leguminosae. For example, the coconut palm supplies nearly all the wants of the inhabitants of the villages where it grows.

(1) *Cocos nucifera*—Coconut.

(2) *Borrasus flabellifer*—Palmyra.

(3) *Calamus rotang* and allied species—Cane.

(4) *Areca catechu*—Arecanut.

(5) *Phoenix dactylifera*—Date.

(6) *Metroxylon Sagu*—Sago

(7) *Raphia pedunculata*—Raffiia fibre.

(8) *Caryota urens*—Kittool fibre and Bastard Sage.

(9) *Elaeis guinensis*—Oil palm.

(10) *Oreodoxa spp*—Ornamental.

4. **Araceæ.**

Characters of the family.—Herbs with milky or watery or bitter juice with a tuberous or elongated rhizome, rarely woody and climbing; *Leaves* solitary or few, moslty *radical*, sometimes alternate and distichous or *spirally arranged*, entire to variously divided, often *hastate* or *sagittate* with a membranous *sheath at the base. Flowers*, small or minute, often with a bad odour, *arranged on a spadix enclosed in a spathe* either hermaphrodite and all alike, or monoecious the males in the upper part of the spadix, the females below, rarely dioecious. *Perianth* present in the hermaphrodite flowers, segments 4—6 or connate into a truncate cup, mostly absent from the unisexual flowers: *Stamens* hypogynous 2—4—8, *opposite the perianth* segments; *anthers* opening by pores or slits, free or united into a mass; *staminodes* sometimes present among the female and below the male flowers; *Ovary* superior or immersed in the spadix, 1 to many celled; *style* various, sometimes absent; *ovules* parietal, axile, basal or apical; *Fruit* a berry 1 to many seeded; *seeds* endospermous.

Distribution.—Temperate and tropical regions, more abundant in the latter.

Type.—*Colocasia antiquorum*, Schott.

A very common perennial herbaceous plant, growing wild in wet lands and other marshy situations, also cultivated for its cormiferous stem which is widely used as a vegetable (root crop): *Stem*

cormiferous; *Leaves* ovate to suborbiculor, cordate, large 6—20 in long, 3—12 in. wide, dark green, petioles stout 3—4 ft. long, green; *spathe* 8—18 in. long, tube oblong; *spadix* free, shorter than the spathe, male and female flowers with interposed flat neuters; *Perianth* 0; *Stigmas* sessile, flat, 3—5 ranged; *Fruit* a berry, seed endospermous.

Useful Plants.—

(1) *Amorphophallus Campanulatus*—Elephant yam—Vegetable.

(2) *Pothos scandens*—Ornamental.

(3) *Acorus calamus*—Sweet flag—Medicinal and insecticide.

5. Cyperaceæ.

Characters of the family.—Generally perennial and rarely annual herbs, usually in damp or marshy habitats, often tufted or from a creeping rhizome; *stem* solid or rarely hollow, often triquetrous, mostly simple below the inflorescence; *Leaves* usually in a basal tuft or crowded on the lower part of the stem; sheath closed or open at the base and blade narrow grasslike; *ligule rare*; *Flowers* very small and *inconspicuous*, hermaphrodite and unisexual and monoecious, very rarely dioecious, arranged in small *spikes* (*spikelets*), and each usually solitary within a *bract* (*glume*); bracts (glumes) *distichously or spirally* arranged; *spikes* variously umbellate, paniculate or rarely spicately arranged; inflorescence subtended by one or more usually leaf like involucral bracts; *Perianth* reduced to *scales, bristles or hairs*, often absent; *stamens* hypogynous, 3 or fewer, filaments free; *anthers* 2 celled; *ovary* superior 1-celled; *style* with 2 or 3 branches or 2-3 toothed; *ovule* solitary, erect from the base of the ovary; *fruit nut* like indehiscent 2 to 3 sided; *seed* with *endosperm*.

Distribution.—Worldwide in damp situations.

Types.—*Cyperus rotundus*, L.

Fimbristylis miliacea, Vahl.

Cyperus rotundus consists of underground stolons bearing fragrant tubers and a few aerial branches ending in inflorescences. *Leaves* with tubular sheath, three-ranked, crowded at the base of the stem and grass like. *Inflorescence* an umbel of spikelets. A *spikelet* has 10 to 50 glumes distichously arranged and the flowers are in the axils of glumes. *Flowers* of 3 stamens and an ovary

with a 3 fid stigma and without any perianth. *Ovary* superior, 1 celled. *Fruit* a blackish trigonous nut.

Fimbristylis miliacea. Vahl., occurs in moist places and in paddy fields. It is annual and tufted. Leaves shorter than the stem, with sheaths distichously arranged. Spikelets globose with closely imbricating ovate, boat-shaped glumes, in compound open umbels; stamens vary from 1 to 3. Fruit is an obovoid, yellowish, tuberculate nut. Style three-fid.

Useful plants.—Several species used in the making of mats Cyperus rotundus is medicinal.

6. Gramineæ,

Characters of the family.—Annual or perennial herbaceous plants and in the latter case, the growth is often sympodial and the stem is a rhizome as in *Cynodon dactylon* (Hariali), *C. plectostachyum*, star grass, the bamboo sp., which bears a succession of aerial branches (culms), the rhizome being composed of the successive lowest internodes of the culms. The culms end in infloresccnses. The culms of grasses are mostly *hollow* as in rice plant while a few are *solid* as in sugarcane; the *leaves* are alternate, distichous, consisting of *sheath*, *ligule* and *blade;* sheaths encircling the culm with the margins free and overlapping or more or less connate; *ligule* is the structure that is placed at the junction of the sheath and blade and is either membranaceous or reduced to a fringe of hairs and very rarely absent; *blades* usually long and narrow as in rice, rarely broad as in sugarcane or *Sorghum*, parallel nerved; the inflorescence is a *panicle of spikelets*, the *spikelet* being the ultimate unit of the inflorescence. Inasmuch as the flower itself is so uniform for the majority of the grasses, it is on the variation in the characters of the spikelets and its component parts, that their classification mainly depends. The spikelet of the grass, for purposes of taxonomy and classification, takes the place of the flower in other angiosperms; *Flower*, the work of protection is carried out by the subtending bracts, and there is no need for any attractive devices in wind-pollinated flowers and so the perianth is reduced to two or three small scaly to cushiony bodies called *lodicules*. The commonest number is two, placed anteriorly, but the presence of a third posterior lodicule, as in some primitive bamboos, bring the flower more nearly back to the normal monocotyledonous type. Rarely are the lodicules absent or are more than 2 or 3. When the flower is ready for pollination, the lodicules become turgid and help to separate the tightly enclosing *lemma* (fertile bract) and palea (the bracteole) and thus open up and

RICE PLANT - Seedling, grain, floral parts

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expose the essential organs of the flower. Later the lodicules collapse and allow the *lemma* and *palea* to resume their protective functions.

In a wind pollinated flower the androecium is modified in such a way as to scatter the pollen in a most efficient manner and the grass flower is usually taken as the best example of efficient wind-pollination. Usually there are 3 large stamens, with large anthers on long filaments, basifixed, but often so deeply sagittate as to suggest versatile. In a few plants as in Rice and Bamboo, there are 6 stamens. If the flower is hermaphrodite, there is the *gynoecium* present along with the stamens. The *gynoecium* usually consists of a single ovary, composed of one carpel (or according to some of three carpels) surmounted by *two styles*. There are cases like the *Pennisetum* and *Zea* where there is a single style produced by the union of the usual two. The stigma is usually of the much branched plumose and feathery type, with the branches in two directions. Sometimes it is of the aspergilliform type with the branches in all directions. The flower may be sometimes unisexual in which case *staminate* and *pistillate* flowers are formed separately as in *Zea Mays*.

The fruit is a *caryopsis* or *grain* with the seed containing plenty of endosperm. The fruit is rarely a nut or berry or a utricle. The last type of fruit is met with in Ragi (*Eleusine coracana*)

Distribution.—All over the world.

Types.—Rice, Cholam and Sugarcane.

Type 1.—*Oryza sativa*—RICE PLANT.

Botanical description.—The entire range of cultivated rices belong to the single species ,namely *Oryza sativa*, Linn. and the range of duration of the commonly cultivated South Indian varieties is from 3 to 8 months.

The plant is an annual herbaceous grass growing to a height of 2 to 6 feet according to the variety. The root system is shallow, adventitious and fibrous and occupies the soil to a depth of 6 to 7 inches. The roots arise from the first, second and third nodes. There are no aerial roots as in Cholam or Maize. The stem tillers freely, 15 to 20 being common. The culm (shoot) is glabrous mostly, slightly compressed and hollow. *Leaves* are alternately arranged in two rows, distichous ; the blade is linear, 8 to 12 inches long and about $\frac{3}{4}$ in. broad. The ligule is long, acute or obtuse, splits easily into two parts and is auricled, the auricles a pair of them, each being hairy, white or green.

The inflorescence is a loose terminal panicle with branches which are borne singly or in pairs. The spikelet is compressed laterally and is one-flowered. There are two small leathery keel-shaped glumes, one keel-shaped leathery lemma and a palet slightly smaller than the lemma but similar shaped and textured. The lemma overlaps firmly the palet. The flower is hermaphrodite. There are 6 stamens in two whorls each carrying numerous (500—900) pollen grains. *Ovary* is superior, bicarpellate, single celled, single ovuled, stylar arms two, filiform, stigmatic branches a pair, free and feathery. The *lodicules*, a pair, fleshy and cuneate.

The plant is normally self-pollinated, slightly protandrous. Provided the weather is bright, the flowers open throughout the day. The flower remains open from 35 to 90 minutes which gives sufficient time to cross-pollinate artificially for purposes of plant breeding. The fruit is a grain or *caryopsis* with the lemma and palet persistent. In each panicle a number of grains (varying according to variety) set. The grain is smooth, longer than broad, elliptical in cross section. There are two longitudinal parallel ridges on each of the flat surface. The major portion of the grain is occupied by starchy endosperm; deficient in fat and protein and not fit for baking and bread making. It has therefore to be boiled. The little protein is in the aleurone layer.

Type 2 :—CHOLAM—*The Sorghums.*

Next to rice the food crop that is most popular is the *Sorghum*—"the Great Millet." The word *Sorghum* has its origin in the Italian word "Surgo" meaning to rise. Because this crop has a very prominent head which rises head and shoulders over any other crop it is quite likely this name was given to it.

Botanical description.—The plant is an erect, herbaceous annual, 3 to 15 feet in height, unbranched. The root system is adventitious, fibrous, well branched and spreading. The stem is solid, slightly furrowed on alternate sides, nodes thickened, internodes short at the base, becoming longer above those of the middle region equal in length. Terminal internode which ends in the *head* is the longest of all. Suckers or secondary stems or branches arise sometimes and these are undesirable as they are heavy feeders and seldom bear earheads. *Leaves* alternate, 2-ranked, linear lanceolate, sheaths long with considerable variation in different groups, ligule short, membranous and fringed, blades long and flat, very much similar to those of *maize*. They are, however, more erect and the midrib is better developed. Inflorescence, a terminal head, compact mostly. In *broom corn* and a few others it is loose. Length of inflorescence varies. It is very long in broom corn,

intermediate in effuse types, short to very short in compact types and as shape depends on length there are loose and spreading, conical and semi-compact, densely oval, etc., panicles. The panicle is erect or inclined. The spikelets are borne on the branches which are arranged more or less in whorls and the spikelets are borne in pairs or in threes, of which one is sessile and one stalked in the former and one sessile and two stalked in the latter. It may be noted here that this is a character shared by other genera like *Saccharum* and *Andropogon*. The pedicels of sessile spikelets may be short or long. *Sessile spikelet* is ovate, elliptic or oblong or obovate according to the species or variety. The number of veins of the glume varies within a definite range for each variety. The colour is also from straw, yellow to buff yellow, mahogany, red and black and some pale. First lemma large, translucent, fringed with hairs, epaleate in all *Sorghums*. Upper (second) lemma small, thin, translucent, 2-toothed at apex and bears a spike, bristle or awn. Presence or absence of awn is an important character, paleate, palea small translucent. *Stamens* 3, on filaments, basifixed, longitudnal dehiscence. *Ovary* superior, one-celled, one-ovuled. Stylar arms two each with a plumose stigma. *Lodicules* two, fleshy and truncate. The fruit is a grain varying much in shape, size, colour and relationship to the glumes. The endosperm is soft and mealy to hard and flinty. Some are so hard that they are unfit for flour. Grains which are soft and mealy are liable to attack by weevil than those which are hard. *Pedicelled spikelets* are of less importance in classification. They are always narrow, longer or shorter than the sessile spikelet. They are either male or neuter reduced to glumes and pales. Number of glumes usually two and pales one or two. *Cholam* is a self-fertilized crop.

Type 3 :—*Saccharum officinarum*, L., the "NOBLE" cane.—

Botanical description.—A tall (annual under cultivation) giant herb reaching ordinarily a height of 12 feet and sometimes even 30 feet under extraordinary conditions.

The weight of an individual stalk may vary from 6—7 pounds and sometimes a weight of 15 pounds has been recorded.,

Number of joints, according to variety—20 joints are very common. *Tillers* fairly well 4 to 6 being common. The *root system* is fairly deep, adventitious, fibrous, depth and extent varying according to the variety..

Stem.—Shape of internode, usually barrel, sometimes cylindrical, other shapes like concave, etc. are not also uncommon colour from pale or dark green to dark yellow, dark red, violet

often striped. Every leaf bears a dormant bud, a little bigger than the size of a large pea. Just above the node there is a root zone which is made out as a collar of 1—3 rings of white spots. Each dot is really a root initial and when favourable conditions for germination are given the adventitious roots are formed from the root initials. All canes are generally covered with a waxy bloom. *Leaves* alternate, distichous, linear lanceolate, sheath fairly long up to 12 inches and blade length varying according to varieties. Midrib prominent and channelled. Surface rough, margin fringed with hairs.

Inflorescene.—Terminal soft silky panicle familiarly known as the "Arrow." Not all canes flower. Cane flowering depends on climate, time of sowing and variety.

The spikelets are arranged in pairs on the branches of the panicle. One is sessile and the other stalked. *Stalked spikelet*—Glumes 1 and 2 as long as the spikelet, green, keel shaped, epaleate, sterile. *Lemma* 1—membranous, transparent, sterile; Lemma 2—absent—Palet of Lemma 2 a small membranous translucent structure. The floral parts are enclosed in between Lemma 1 and palet of Lemma 2. *Stamens* 3, filaments tender, anthers basifixed. *Ovary* superior, stylar arms two, stigmas a pair, plumose. *Ovule* single, Lodicules—2, fleshy, truncate not ciliate in the cultivated canes but ciliate in the wild cane (*S. spontaneum*, L.)

Sessile spikelet.—It is exactly like the stalked spikelet in structure with only this difference and that is Lemma 2 is present as a small membranous bristle-like structure.

The fruit is a caryopsis, resting period very short, from a few days to a month.

Canes are either male sterile or female sterile, a fact which is of very great advantage in sugar-cane breeding. Female sterile plants are used as fathers and male sterile ones as mothers. If one plants judiciously the male and the female varieties to be crossed in such a way that as the wind blows it has to first pass over the male and carry the pollen on to the female placed behind, crossing is automatically done. The famous canes, P.O.J. 2725 and Co. 421 are used as mothers because they are male sterile.

The cane is a plant of the tropics and likes a warm moist climate with moderate intervals of hot, dry weather. The cane has been found to thrive luxuriantly in islands and along the sea coasts of the mainland. It requires plenty of water.

It is distributed in India, Java, Philippines, Formosa, southerly islands of Japan and South China in Asia. In Africa it

SUGARCANE PLANT - Part of stem, arrow, floral parts

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is grown in Egypt, Madeira, Natal, etc., in America in West Indies including Cuba, Barbados, Louisiana, etc., and in Australia in Queensland and New South Wales.

The propagation of the cane is by *setts* which are cuttings or by *tops* which are terminal buds. Every sett should have at least 3 nodes and 2 internodes, so that chances are given for two to three axillary buds to develop.

In the breeding stations, the plants are raised from seeds for work connected with the improvement of the crop by hybridization.

Useful Plants—

All the cereal crops which supply staple food to men and herbivorous animals—Rice, wheat, barley, oat, rye, maize, ragi, cholam, cumbu, varagu, kudiravali, panivaragu, etc. Bamboo, sugarcane and several species of grasses which supply green fodder, while some of them bind soil and prevent erosion.

CHAPTER XXXIV

ELEMENTS OF GENETICS AND PLANT BREEDING

Like begets like.—It has been pointed out in the earlier chapters that plants are concerned mainly with two functions, namely, **Nutrition** and **Reproduction.** As a result of the process of reproduction, a continuous succession of new individuals arises. One of the most remarkable features of this reproductive activity in plants as well as animals, is that each of the new individuals bears a very close resemblance to its parents. The offsprings of rice plants are always rice plants; and the offspring of coconuts are always coconuts. What is more interesting is any particular kind or variety of rice (*Semba*, *Sirumani*) or of coconut (local or Jaffna) will produce plants of that kind or variety. This tendency for offspring to display the particular characteristics which distinguish their parents is termed **Heredity.**

FACTOR

What is it that links one generation with the other? It is indeed a very narrow physical bridge—the reproductive cells, or gametes. It is these that bridge one generation with the other. One parent contributes a single male cell and the other parent a single egg cell and out of the fertilised egg arising from the fusion of the two gametes the new individual develops. It is, therefore, very clear that the parental characteristics must be transmitted in some way through these tiny sexual cells. Any actual plant character such as a resistance to a particular disease or a tall or a short habit of stem obviously cannot be found in these cells; but something representing it and capable of producing it in the new plant, must be there. This "something" whose real nature is still difficult to determine is called the **factor** or **gene** for the character in question. In all our cultivated crops like the cereals, pulses, oilseeds, cotton, etc., a number of characters the tall or the short habit of paddy, the compact or loose panicle in cholam and a host of other quantitative and qualitative characters are found to be inheritable, some species or varieties of particular crops having very desirable characters and some not and some having a combination of some good and some bad qualities and so on. This is true not only of plants but of all organisms in nature.

These minute sexual cells then must have all these characters packed into them and it is really a matter for great wonder that all

these must emerge out again when a new plant grows with all these inherited in it. In fact all these characters are involved in the seed and evolve when the seed grows into a plant.

VARIATION

Though there is a close resemblance between parent and offspring, there is never an exact resemblance. If one studies carefully any individual plant or animal, he will find that the offspring differs somewhat even though very slightly from both its parents and from its fellow offspring. These differences are known as **variations.**

Heredity together with variation plays a very great part in nature, heridity trying to preserve types and variation trying to create new types.

INHERITANCE OF CHARACTERS

Before one can think of plant breeding one has to know how characters are inherited. It may be argued that in the past, plant and animal breeding went on without a knowledge of the laws of inheritance and that these also sometimes met with success. But is it not wise to proceed with a full knowledge of the laws governing inheritance so that one can be sure of the results he is going to achieve instead of leaving it to a sheer chance of success or failure ?

When a plant gives rise to identical plants in the next generation, then we say it **breeds true.** The term may be used with reference to all characters or some particular characters, for example, a type of cotton may breed true for yield but not for lint length and so on. So the term "breeding true" may be for one or more or for all characters. It was already pointed out that the slender bridge between generation and generation is made up of the germ cells. Any hereditary character or material which is passed on must be carried by the germ cells, the pollen and the ovules. If a plant **"breeds true,"** then it means that its germ cells are all alike in respect of the particular characters concerned. An easy way of picturing this is to use letters to indicate the plant characters. For example, let us suppose we have in mind a paddy plant that breeds true for a tall habit. We can easily say that all its pollen grains carry something which controls the tallness of the plant and this something may be represented by the letter T (for tallness). Similarly all the ovules carry the same "something" that is, they carry T. It is obvious at a glance that if a T ovule is fertilized by a T pollen grain, then the individual that results from fertilization will be TT. Such a plant will breed true to the tall habit

since it can only pass on T to its germ cells. To sum up, **it may be said that plants which breed true for a given character must have received the same hereditary material from both male and female parents.**

If a self-pollinated plant does not breed true, then we say it **segregates.** Just as a plant may breed true for one or more characters, so it may segregate for one or a number of characters. For example, a tall variety of paddy might give progenies some tall and some short. Now it has been already shown that the gametes of a plant that breeds true are all alike. Therefore, it necessarily follows that the gametes of a plant which does not breed true must segregate or to use our letter symbols instead of all the ovules and pollen carrying T, some of them are, let us say, carrying for the dwarf habit. If one of these dwarf plants should be found to breed true for the dwarf habit, we should naturally suppose that all its germ cells carried it and the hereditary constitution of all its progeny would be tt. All tt plants would therefore breed true for the dwarf habit.

GENE SYMBOLS

This something which is carried by the germ cells from one generation to another is called a **gene.** No one has ever seen a gene, just as no one has ever seen an atom. From a good deal of experimental evidence, it is clear that genes are tiny specialized particles of living matter which govern the growth and development of the plant in every kind of way. At a moderate estimate there are between five and ten thousand genes controlling the development and inheritance of a tiny fly. Usually a gene affects at least several characters. Thus when we talk about the gene T for tallness, we are really identifying it by its most striking effect. As a matter of fact, it may control a number of other characters. Conversely, a character may be controlled by a number of genes, some having large and others small effects upon it. It is therefore clear that the plant is a well balanced piece of mechanism, the appearance and working of it at every stage of its life depends upon the play and interplay of thousands of genes. We may define a gene as follows :—**A gene is the unit of inheritance, which is passed *via* the germ cells from generation to generation to produce its characteristic effect.**

Because each plant is a product of the fusion of two gametes half of its hereditary material is supplied by the male and half by the female. Therefore genes occur in the vegetative parts of a plant in pairs, one member of the pair being contributed by the

male and the other by the female parent. In wild species, the members of a pair of genes are identical, *e.g.*, AA, BB, CC, DD, etc. Rarely however a gene may change in its structure. It is then said to *mutate*. We may represent the gene by a capital **A** and the mutant gene by a small **a**; genes such as these constitute a pair of contrasting members and they are called *allelomorphs*. Such genes control the contrasting pairs of characters such as tall and dwarf. We usually represent the members of a pair, by capital and small letters, **T** for tall and **t** for dwarf. Examples of the effects of allelomorphic gene-pairs are hairiness—smoothness, entire leaves—compound leaves, early maturing—late maturing, colour—no colour, etc.

MENDELISM

Gregor Mendel selected for investigation closely related forms and discovered certain definite laws, which he published in 1865. These results did not attract attention until 1900, when they were re-discovered simultaneously by the three investigators, namely: De Vries, Correns and Tschermak.

Before Mendel, several workers in this field of research thought that hybrids were intermediate between the parents, though they resemble the parents in some features, and that crossing of distinct races was a potent cause of variability. But they could not arrange their observations in any order so as to bring them under definite laws. This is because they always regarded the individual as the unit, and we know that an individual may have many characters. On the other hand, Mendel took as his unit, not the individual, but one character found in an individual, and he always concentrated his attention upon one character at a time. *He viewed an individual as being to a very large extent an aggregate of separate characteristics.*

SEGREGATION

To understand the work of Mendel it is necessary to consider some illustrative examples. He crossed a pea plant possessing seeds with yellow cotyledons with another pea plant bearing seeds with green cotyledons, and the resulting fruits in the hybrids bore seeds containing yellow cotyledons only, in spite of the fact that one parent had green cotyledons. It made no difference which was the pollen and which the ovule parent. When the hybrid (F1) plants were selfed and the seeds sown, the resulting progenies were of two types; some plants bore seeds with yellow cotyledons and others bore seeds with green cotyledons. All the hybrid plants bore seeds with yellow cotyledons, while the progenies

from them bore seeds with either yellow or green cotyledons. The yellow was called the **dominant** character because it dominated in both the generations, and the green **recessive** on account of its being hidden in the first generation. Such characters do not blend, but remain quite distinct and independent and are spoken of as **unit characters.** Alternative pairs of characters such as the above, yellow and green that behave as dominant and recessive have been named **Allelomorphs.** In the second generation progenies, seeds with yellow cotyledons and those with green cotyledons appeared in a definite ratio. There were three plants with yellow cotyledons to every one with green cotyledons. By further selfing it was found that plants with green cotyledons produced plants with green cotyledons only. But out of the yellow, only one bred true, and the remaining two did not breed true, when selfed. Instead of producing only yellow seeds they produced seeds with yellow and green cotyledons in the proportion 3 to 1. These results may be expressed in a tabular form as shown below :—

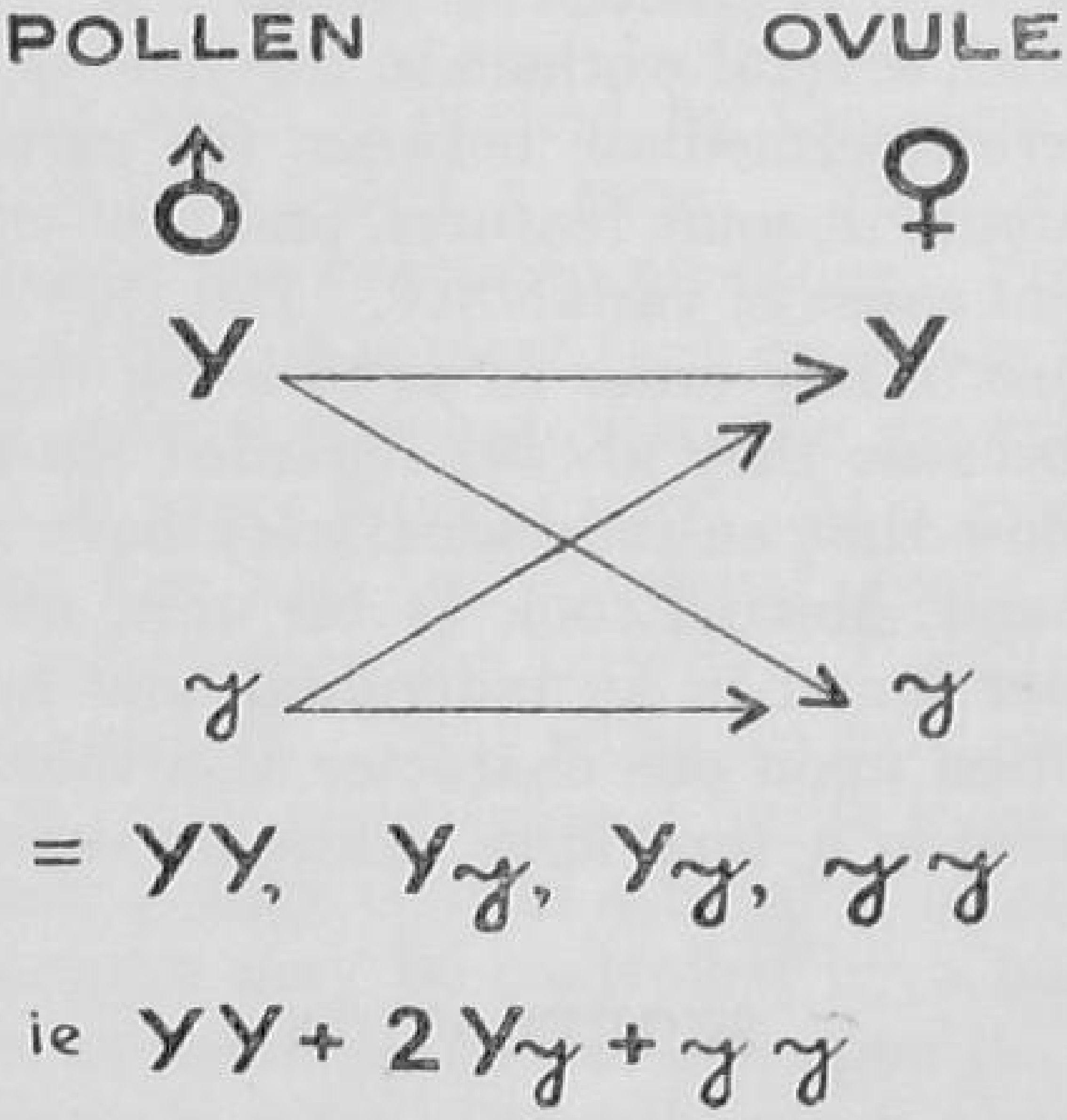

Fig. 396. Simple Segregation.

From the results stated above, it is obvious that, when hybrids are propagated by seeds, only one half of the progeny will show the hybrid character, the remaining half resembling the pure parents.

Sometimes the hybrids possess a character intermediate between those possessed by the two parents. For example, if a white flowered *Mirabilis Jalapa* is crossed with a red-coloured one, the hybrid plants bear rose-coloured flowers only. When these are

selfed, the individuals of the second generation produce plants bearing red, rose and white flowers in the proportion of 1 : 2 : 1 respectively. Amongst the plants of the second generation the red and the white flowered plants breed true on selfing, whilst the plants with rose coloured flowers on selfing produce all the three coloured flowers in the ratio 1 red : 2 rose : 1 white.

To explain the above results Mendel conceived the idea that the gametes could contain the factors of only one of the two contrasting characters, and not both of them. So when fusion takes place between the male gamete and egg in the ovule possessing the factors for yellow, the resulting fertilised egg-cell or the **zygote** must necessarily contain a double dose of the same kind of genes or factors. Such a zygote as this is termed a **Homozygote.** If, on the other hand, the pollen-grain contains factors for yellow and the ovule for green, or *vice versa*, the zygote will contain factors for both the characters and this kind of zygote is called a **Heterozygote.**

In the hybrid plant both the factors for yellow and green are present in all the cells of the plant. But in the course of the formation of the pollen-grains and the ovules, reduction division takes place and therefore, the factors get separated. So the sexual cells will have either the factors for yellow or green and never both. This dissociation of the factors from each other is spoken of as the **Segregation.** This is Mendel's first law. As the result of this segregation in the sexual cells, we should expect the number of reproductive cells bearing the factors for yellow to be on the average equal to those carrying the factors for green. Therefore, when the hybrid plants are selfed, the union between the gametes of the pollen-grains and those of the ovules could occur only in four ways. So there will result one seed pure to yellow, one pure to green and two with both yellow and green. This is exactly Mendel's ratio namely 1 : 2 : 1. Since the yellow colour is dominant and the green colour recessive, the hybrids will have only yellow seeds, though they contain the factors for green. So the ratio of yellows to greens would be 3 : 1. But in the case of *Mirabilis Jalapa* plants above mentioned, the ratio would be 1 red : 2 rose : 1 white. These facts are graphically shown in diagram on page 518.

Although the theory of segregation and purity of gametes were mere speculations at the time of Mendel, we now know that the separation of the chromosomes occurs in the formation of spores or sexual cells.

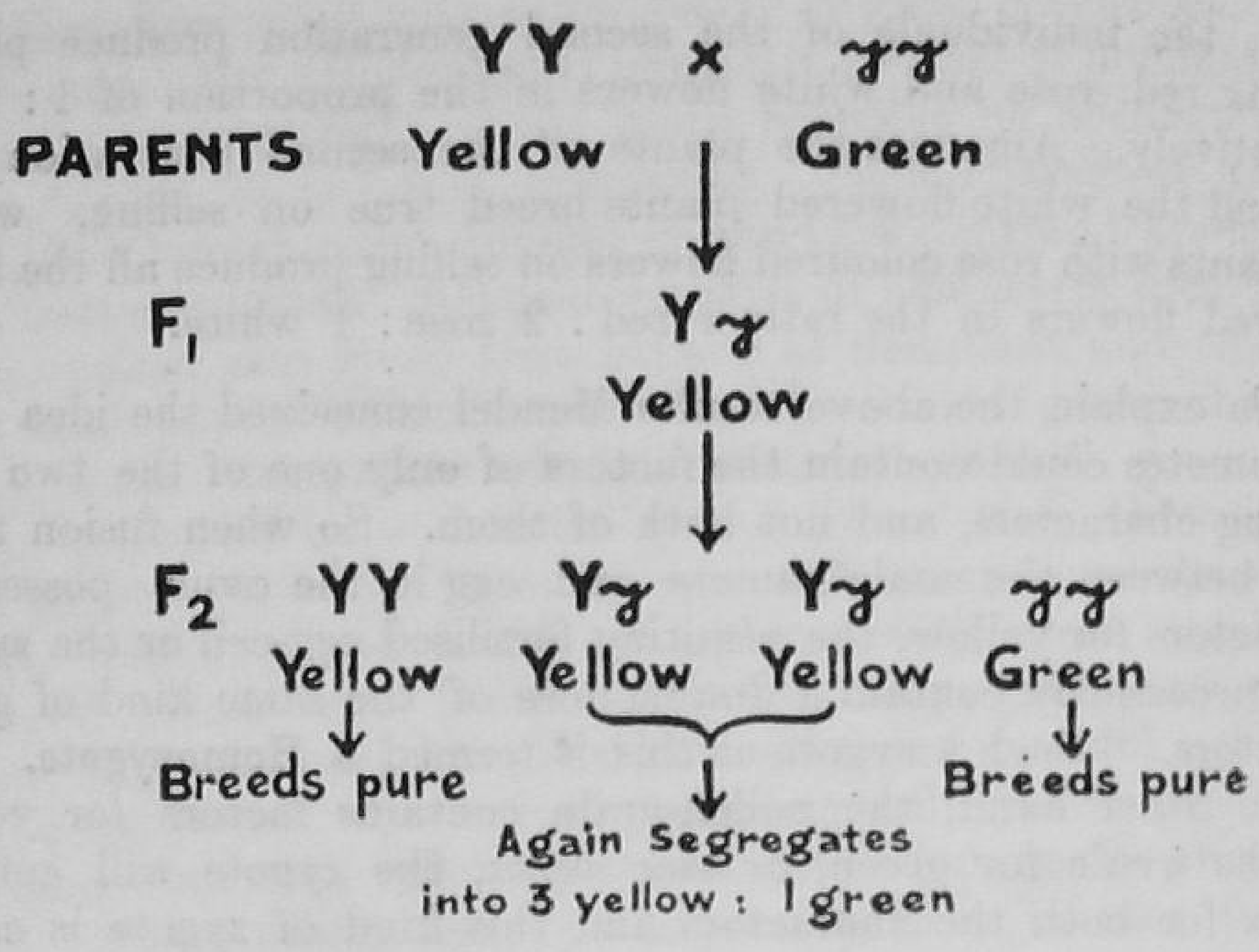

Fig. 397. Monohybrid Segregation.

These usually contain only half as many chromosomes as there are in the somatic cells. The nature of the zygote will depend upon the nature of the gametes that have fused to form the zygote.

INDEPENDENT ASSORTMENT

In the illustrative examples, so far considered, we paid attention only to one pair of contrasting characters for the sake of clearness. Such hybrids are called **monohybrids.** But every plant is an aggregate of characters and so in the crossing of plants several pairs of such characters may be involved. Whatever may be the number of pairs of such characters, the behaviour of each pair conforms to the laws of Mendel already described. We may next consider the case of **dihybrids.** Mendel crossed plants having peas possessing yellow cotyledons round in shape with pea plants bearing green cotyledons and wrinkled shape. The hybrid plants produced only round yellow peas. The characters, wrinkledness and green colour, did not appear in any of the seeds of the hybrids. On self-fertilising the individuals of the first generation, four distinct types of plants appeared in the second generation. They were : (1) round seeds with yellow cotyledons, (2) round seeds with green cotyledons, (3) wrinkled seeds with yellow cotyledons, and (4) wrinkled seeds with green cotyledons. The first and the fourth are similar to the parents, but the second and the third are new combinations. When the proportion to one another of the plants produced in second generation was considered, it was found to be as follows :

9 round yellow; 3 round green; 3 wrinkled yellow and 1 wrinkled green. If we represent the two pairs of allelomorphs yellow vs. green cotyledons and round vs. wrinkled seeds by using the symbols Y-y and R-r respectively, the F2 combinations will be as shown in the checker board below:

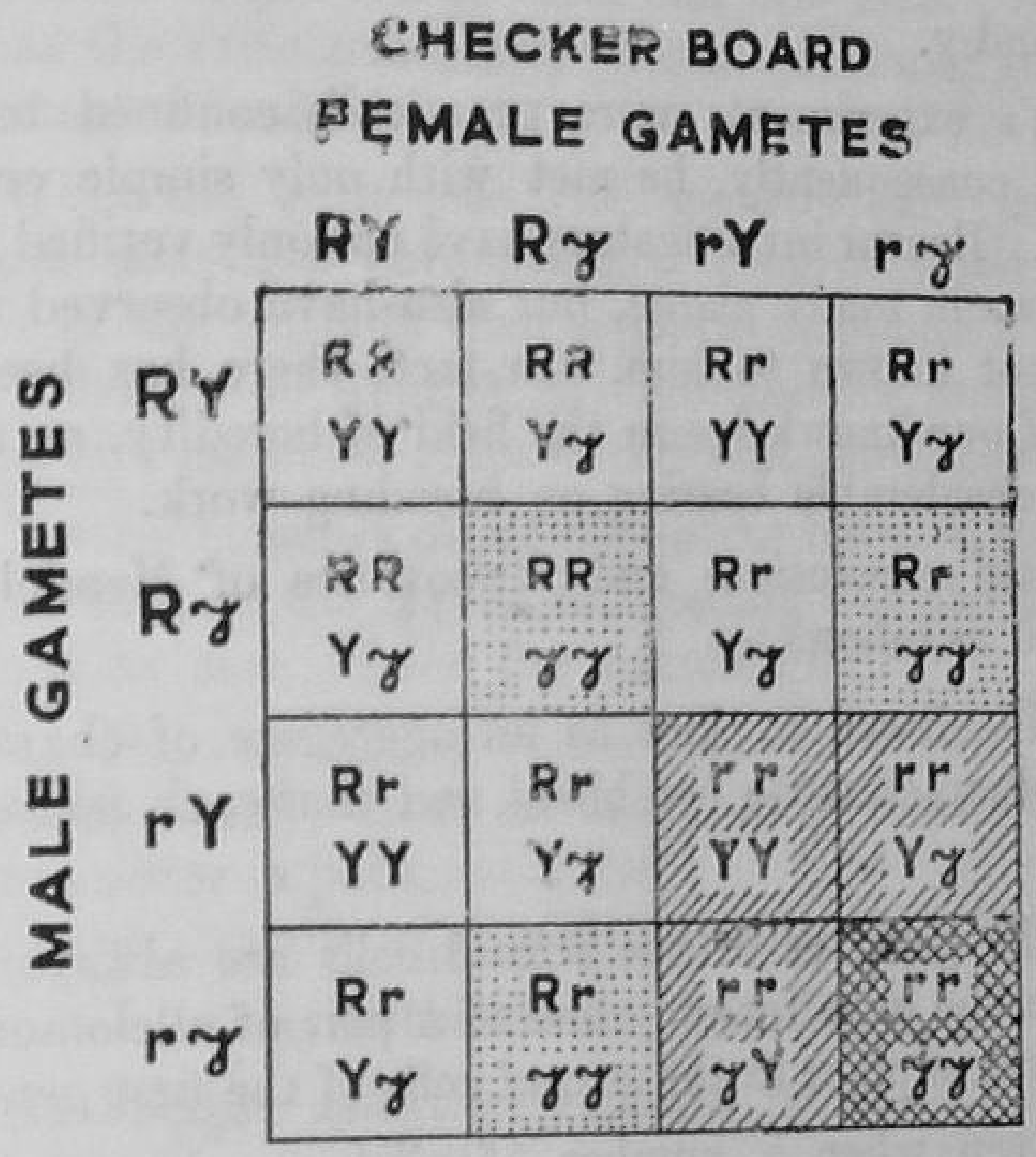

Fig. 398. Dihybrid. Independent Assortment.

Thus we see that when two allelomorphs are concerned in crossing, the segregation of factors in one pair is independent of segregation in the other pair, *viz.*, a gamete with factor Y may carry the factor *R* or *r*. This is Mendel's second law of **Independent Assortment.**

The nine combinations that are in the white squares would be alike in external appearance and all of them would have round seeds with yellow cotyledons. This is, because, both the dominant characters R and Y occur in the combination. Out of these nine, only one having the combination of pure dominants RRYY, *i.e.*, homozygous for both characters, will breed true. In the remaining eight, two are homozygous for R only, two for Y only and four heterozygous for both pairs of characters.

The three, RRyy, Rryy, rRyy found in the squares with dots would have round seeds with green cotyledons, R being dominant over r. The character yellow seed is absent. One is homozygous for both R and y and all the three homozygous for y only.

The three rrYY, rrYy, rryY found in squares with oblique lines would be wrinkled seeds with yellow cotyledons, Y being dominant over y. The character round seed is absent. One is homozygous for r and Y and all the three homozygous for r only. One rryy in the square hatched with crossed lines is a wrinkled green seed. Both R and Y are absent. This is homozygous for both r and y.

Mendel's experiments were practically confined to the pea plants and, consequently, he met with only simple condition of inheritance. Recent investigators have not only verified repeatedly Mendel's laws in many plants, but also have observed many new situations not known to him. In fact, there has been a great extension of our knowledge in the field of heredity, as this knowledge has considerable bearing on breeding work.

The main conclusions and discoveries of Mendel may be briefly stated as follows :—

(1) He viewed a plant as an aggregate of characters and found that characters do not blend and that each factor behaved as a unit.

(2) The gametes or the sexual cells are always pure and they contain the gene for only one of a pair of allelomorphs ; *i.e.*, **segregation** takes place in the sexual cells of the first generation.

(3) Even when a number of allelomorphs are concerned segregation in any one pair is independent of segregation in any other pair.

The value of the discoveries of Mendel is very great. Characters found in different plants may be combined in one plant, taking advantage of the fact that contrasting characters behave independently. **New types of plants may be produced by the recombination of characters.**

THE CHROMOSOME THEORY OF HEREDITY

In the discussion on the principles of heredity and Mendelism, we learnt that the many characters of a plant are determined by the gene it carries ; that the genes are the units of inheritance passed on from one generation to another. It follows, that such orderly behaviour as we find in inheritance must be the result of a very accurate mechanism. The **chromosomes** constitute this mechanism. The essentials of the **chromosome theory of heridity** are as follows :—

(1) The genes are located serially on Chromosomes.

(2) There are two of each kind of chromosome in each body cell of the plant—one derived from the male and one from the female parent.

(3) When the body-cells divide, each chromosome divides along its length into identical halves, which separate and pass to opposite ends of the cell to form two new cells. Hence every body-cell has the same number of chromosomes and genes. (This is the resultant of **mitosis**).

(4) When the germ-cells (the gametes) are formed, the paternal and maternal chromosomes come together in pairs at the equator of the cell and then separate to opposite ends of the cell, thus halving the number of chromosomes and distributing the paternal and maternal genes to different germ cells (**Meiosis**).

(5) A striking series of parallels occur between the behaviour of factors as seen in the results of breeding and the behaviour of chromosomes as seen under the microscope.

(*a*) The contrasting characters are in pairs (colour—no colour, smooth—hairy, short duration—long duration) and the chromosomes occur in pairs.

(*b*) The two factors of each pair segregate in the formation of gametes and so do the chromosomes.

(*c*) Factors assort at random, so do the chromosomes at the first division of meiosis.

(6) In the phenomena of **linkage** and **cross-over** again we see a close parellelism between the behaviour of the factors and those of the chromosomes.

These essential facts show that chromosomes carry the genes and that they therefore form the subtle mechanism of inheritance in plants and animals.

PLANT EVOLUTION

It has been pointed out that among all organisms, new variations are continually appearing and being inherited. This leads to the conclusion that living things are not constant and changeless in their characteristics but that they may undergo a certain degree of permanent modification as the generations succeed each other. Heredity and variation have been potent factors in briging about evolution. If we take, for example, the sour, fibrous mango fruit with large stones growing still wild in the forests and compare it with some of the sweetest table varieties which have no fibre and are all sweet, one wonders how these latter have been evolved under human guidance and what a long

time must have lapsed before these resulted. In fact we are not able to trace the wild ancestors of many of our cultivated plants because in evolution they have become so much changed that they appear as absolutely new species and their old relationships have to be constructed with our imagination. The old theory, the theory of the orthodox religionists that everything was created has been blown up and though one is not able to understand fully the various causes of evolution, still the *fact* of evolution remains and every scientist believes in it and knows that there is always going on a steady upward progress from lower to higher types of life.

(i) **Geological evidence**: Among evidences for evolution *geological evidence* is the first and foremost. Though there are enormous gaps in this record, "the main scenes in the pageant of evolutionary progress" are there. One is able to trace the development of vascular plants from lowly forms and to recognize approximately the point at which angiosperms first appeared upon the earth.

(ii) **Taxonomic Evidence.**—The general character and classification of the plant kingdom bear testimony that the present state of plants is the result of descent, with progressive modification, from earlier types. A study of the external and internal morphology of plants makes it clear that they are not haphazard and random in their characteristics but that they fall into well marked *groups* of similar forms, the members of which show definite resemblances to each other. All similar individuals are classed together as a **species.** A number of species resemble one another so much and are usually so different from anything else that they are placed together as a **genus.** A number of genera in the same way make up a **family.** Families are grouped together into orders, orders into classes and so on. Thus we are able to establish a close taxonomic relationship between the various plants on the earth which makes us think that there has been an evolutionary descent with progressive modification.

(iii) **Embryological evidence**: This is studied better with examples from the animal kingdom. A good example of seedling "recapitulation" is furnished by the plant *Acacia melanoxylon*, R. Br. (The Black wattle) a tree of Australia very common in the hills of South India. In the first few (seedling) leaves one sees the bipinnate compound leaves characteristic of the genus but the later leaves are phyllodes.

(iv) **Evidence from geographical distribution**: We have separation of individuals from the general mass of their relatives

by barriers such as mountains and sea and we see that these individuals are localized. Such localized distribution can be explained only on the assumption that these plants were actually evolved in the regions in which they now inhabit and have been confined there ever since by barriers of various sorts. As examples, we may note the Eucalyptus in Australia, Jak in India, etc.

(v) **Experimental evidence.**—Following Mendel's laws and employing modern methods to bring about **mutations** there has been in the experimental field a good many new forms—new creations. From a study of these, it is clear that in nature hybridisation and mutations must have been going on through millions of years as a result of which new forms should have arisen.

(vi) **Lamarcks's Theory—Acquired characters.**—The French biologist, Lamarck, (1744—1829) put forward the theory that acquired characters are inherited. By use and disuse of organs through successive generations the organism undergoes a change. That this is not possible was shown by Weismann who experimentally proved that acquired characters are not inherited.

(vii) **Darwin's Theory—Natural Selection** :—The theory of Natural Selection, one of the most famous theories on Evolution, was put forward by Charles Darwin in 1859 in the "Origin of Species" a book which has had a tremendous influence on all human thinking. The theory involves the principles, namely, struggle for existence, and survival of the fittest.

Darwin argued that these plants and animals which had the best variations were able to survive in the struggle for existence. The struggle for existence involves a competition between individuals for space and food and those which are best adapted survive in the struggle and the others fall. Those which survive are called the "fittest." The phenomena of struggle and survival are evidenced generation after generation. This naturally implies that variations also arise through the successive generations. Variations which are of adaptable value to the organism survive. These adaptable variations which arise in the course of one generation were taken by Darwin to be inherited through **Pangenes.** This hypothesis on pangenes implies that acquired characters are inherited. Darwin could not explain how new heritable variations arise in the organisms. This explanation was provided by Mutation theory of De Vries.

(viii) **De Vries's Theory—Mutation.**—De Vries, the Dutch Botanist, showed that heritable variations arise by *mutation.* These are permanent and inheritable and are often large and

conspicuous. According to this theory organic nature advances by distinct and usually rather long steps rather than by an almost infinite number of short ones.

(ix) **Hybridisation and Evolution.**—By hybridization genetic factors are brought together in new combination. Such new combination of genes, sometimes results in a new type of plant not hitherto existent in Nature. Many of our crop plants, such as mustard, sugarcane and cottons were evolved in this manner.

(x) **Orthogenesis.**—There are some biologists who think that the directive factor in the production of new forms emanates from the organism itself. According to them, there is an internally directed evolution—the evolutionary change being due to the unfolding of certain tendencies in the protoplasms of the plant or animal and is not forced upon the organism **from without.** This is the theory of **orthogenesis.**

One has to admit that the problem of evolution is not easily solved. It is left to future when there will be an increased knowledge in heredity, cytology, physiology, etc., to offer a very complete and satisfactory explanation on the subject.

IMPROVEMENT OF CROPS

The important methods employed in the improvement of crops are as follows :—

(1) Introduction and acclimatisation.

(2) Hybridization.

(3) Mass selection.

(4) Pure line selection.

The plant breeder may have to employ one or more of these methods according to the nature of the crop.

1. Introduction :—A very good example is to be had in the American Cottons introduced into India. The **Cambodia** particularly and the **Bourbon** have taken to climatic and soil conditions of certain regions quite successfully. The plant breeder here is not satisfied with mere introduction but has been pursuing his work by another method, namely, single plant selections as a result of which we have the strains CO_2, CO 920 etc.

2. Hybridization :—The method of **hybridization** was already discussed under mendelism. By crossing two different varieties or species or genera new combinations are achieved. To illustrate

let us take the hybridization work done in rice. In the case of paddy, a variety of Paddy (Korangu samba of Tanjore) susceptible to a particular fungus disease, namely, the Paddy Blast (*Piricularia oryzae*) when crossed with varieties like G. E. B. 24 gave a progeny which after selection have proved to be comparatively resistant to this disease. Another example is to be found in what is popularly called in Circars as Badavama Kusuma (M. T. U. 16) which was isolated from a natural cross between a local cultivated variety, Konamani and a floating type of Burma. The hybrid pure strain exhibits tall growth ; gives thick straw and stands occasional submersion in water. The rice is pure white. Instances like this can be multiplied with examples from millets, oil-seeds, etc. Hybridization is a very potent tool in the hands of the plant breeder and it has always to be employed with selection.

Similar work has been done on vegetatively propagated crops like sugarcane. There are varieties of cane in Northern India which are very thin and whose sucrose percentage is low. There are the thick 'noble' canes of south India which are thick and richer in sucrose. But the method of introduction—(*i.e.*) transferring the South Indian cane to Northern India is a failure, inasmuch as the South Indian cane is unable to withstand the severe cold weather of Northern India. So the method adopted by the cane breeder was hybridization. The economic canes for Northern India and other places were evolved therefore at Coimbatore by crossing the 'Noble' cane *Saccharum officinarum* with the wild reed cane *Saccharum spontaneum* (2) *Saccharum officinarum* with *Saccharum barberi* (the North Indian canes) and (3) *Saccharum officinarum* with *Saccharum barberi* and this back crossed with *Saccharum spontaneum*. These are simple cases of hybrids and many of the CO. (Coimbatore) canes are complex hybrids involving repeated hybridization between these groups themselves.

3. **Mass Selection:**—This is the old method that has been followed for centuries by ordinary farmers. It consists in selecting the seeds from the best plants in the field. The selection is mostly **empirical** and one is not sure of the purity of the progenies. So long as there are no other improved strains in a locality, this method is useful and can be practised by the ryots in their fields.

4. **Pure Line Selection:**—This is one of the very useful instruments of the breeder This is employed when a particular variety desired is mixed up in a heterogeneous population. The seeds of

each head are sown in lines (head to row) and the plants when they come up are studied with reference to the standard and those that do not conform to the standard are 'rogued out'. This operation is repeated for four or five years, each year eliminating the comparatively useless types until at the end of the fifth year, a stage is reached when they are all homozygous for the characters studied. Single plant selection is practised with success in self-pollinated crops, such as most of the common cereals, like paddy, wheat, cholam, ragi, etc. It is difficult in maize or cumbu which are only cross-pollinated. It can be practised in all pulses, cotton, and other crop where self-fertilisation is the rule. The limitation of this method is, it can only purify and arrive at a particular good standard. Further improvement such as, for example, a resistance to a disease or an increased yield, etc., are not possible here. These are obtainable only through hybridization.

SECTION VIII

ECOLOGY

CHAPTER XXXV

PLANT ECOLOGY

Introduction:—Ecology is that branch of science which deals with the relationship of the organisms to the external environment. The term *Ecology* is derived from the word *oikos* meaning a house. The environment in which the plant or animal lives is compared to a house and hence it is that this science is so named. That science which deals with the relationship of plants to the external world is called '*Plant Ecology*' and when it concerns animals it is called '*Animal Ecology*'.

While morphology and physiology are helpful in understanding the form, structure and functions of the plants and its component parts, and taxonomy in the grouping of plants according to their blood relationship to one another, Ecology is useful to understand the plant responses to its surroundings. While physiology is studied in the laboratory, Ecology is studied in the open fields, forests, mountains, streams, ponds and oceans or in other words in the natural environments in which plants grow. A knowledge of the other aspects of plant life, namely, morphology, histology, physiology and systematic botany is very essential for a full and clear understanding of ecology.

ENVIRONMENTAL FACTORS

The factors which are responsible for plant growth and development are also termed *Ecological* or *habitat* factors. These are mainly : (1) Climatological factors, (2) Topographical and soil factors, and (3) Biotic factors or biological factors.

I. Climatological factors

These relate to : (i) the geographical position, latitude, longitude, etc., so that one knows whether it is a tropical, sub-tropical, temperate or arctic climate, (ii) humidity, (iii) light, (iv) wind, and (v) rainfall. Particularly temperature and rainfall have comparatively the greatest influence on the vegetation of a place. The tropics are rich in vegetation because of the high temperature and the heavy rainfall as, for example, the rich evergreen forests of the Western Ghats. The seasonal distribution of the subfactors of climate are responsible for the variations in the vegetation of a country. In India, the monsoon winds, the South-West and the North-East, have been responsible for the different kinds of vegetation met with in the country, because the monsoon winds bring in rain to the places

where the effect of the monsoon is felt. Places not touched by the monsoon are comparatively barren and places which enjoy the full benefit of both the monsoons are most luxuriant.

A lower relative humidity increases the rate of transpiration and likewise a high wind. Wind affects the shape and mode of branching of the crown in trees, *e.g.*, *Acacia planifrons.* In situations subjected to the play of high dry wind the vegetation is poor made up of low lying shrubs and herbs with bulbous or rhizomiferous stems. Trees are conspicuously absent except for a few odd species like *A. planifrons.* (Compare the vegetation in parts of Ramnad, Dharapuram in Coimbatore District, etc.).

Temperature plays not a little part as it affects the rate of transpiration and based on temperature we call a vegetation, tropical or temperate. In South India, we have the tropical kind of vegetation in the plains made up of the palms, bamboos, sugarcane, banana, coffee, mango, rubber, pepper and so on while on the hills we have the temperate vegetation made up of the characteristic Conifers, *Eucalyptus*, tea, pear, peach, apples, potato and so on.

There are the lower and higher limits of temperature below or higher than which plants do not grow and these are termed the minimum and maximum temperatures for plant growth (*see* chapter in Physiology). Light is essential for the formation of chlorophyll and carbon assimilation and flower and fruit production. There are plants which want plenty of light which are called sun plants and there are others which grow in shade called the shade plants as, for example, mosses and ferns. Their different responses to light is by far the most important of all the climatic factors. Water is the basis of all life. Places which are fortunate to have heavy rainfall have splendid vegetation and where the rainfall is most poor, the place becomes a desert. Where the rainfall is evenly distributed it is most beneficial. Thus rainfall has a great and direct bearing on agriculture.

II. Topographic and soil factors

It is a well-known fact that the surface of the earth is even in some places and in some other places thrown into folds (ups and downs). There are regions with prominent mountains and valleys. Soil erosion first takes place and consequently silting up and accumulation of sand, stone and organic matter are caused by the deposition of the surface matter of the land in valleys and these in turn influence the vegetation. The valley is thus generally more fertile than the slopes since minerals and organic matter

are constantly washed down the slopes by erosion with every rain or high wind. Likewise the deltas, where the land is level and covered up by a net work of waterways is rich in vegetation. (*cf.* Cauvery, Godavari and Tambaraparani deltas). *Soil factors* relate to the physical and chemical properties of the soil. All plants except the ephiphytes and a few parasites are rooted to the soil and are dependent for their supply of food on the soil. The physical properties of the soil, namely, the texture and structure of the soil particles affect the water holding capacity of the soil. Sandy soils drain off water easily and clayey soils retain water. There are plants adapted to each kind of soil.

III. Biotic or Biological factors

There is a close relationship between plant life and animal life. In the lessons in morphology it was pointed out how the insect world, especially the bees, moths and butterflies visit flowers for pollen and honey, their food, and help the plants as we believe in pollination. Not only the insects but higher animals, cattle and goats depend on plants for their food but the vegetation of a locality may be destroyed by the grazing of such quadrupeds. The distribution of fruits and seeds by animals is another instance to show the close relationship that exists between plants and animals. The soil bacteria and fungi about whose importance we have learnt in physiology are again examples of biotic factors. On the top of all these and the most important biotic factor is man himself. He can make the vegetation of a place very rich or destroy it and make it miserable.

Adaptability in plants.—When all environmental conditions, such as temperature, light, humidity, etc., are congenial, plants grow happily. For every factor there is a maximum, optimum and minimum limit. Nature is not all uniform in all places. There are large variations in temperature, rainfall, humidity and light which are made out as distinct geographical regions while there are smaller variations in these factors which mark out the more fertile and less fertile areas of a particular country. Except where the factors are below or above the normal requirements earth is covered with vegetation. The fact that vegetation is met with everywhere in all situations, good, bad and indifferent, only shows the remarkable adaptability in plants.

The ecological factors influencing the growth and development of plants are not few and their combinations are many. Consequently the ecological groups of plants also must necessarily be many. Since these sets of factors impress their marks on the

plants, we should naturally expect all plants subjected to the same set of factors to have some striking characteristics of the same sort, although the plants may be of different families. For example, the aquatic plants, *Nelumbium indicum* and *Trapa bispinosa* have the same kind of structural adaptations in their vegetative organs, though they belong to widely separated Families. The submerged aquatic plants, *Ceratophyllum demersum* and *Hydrilla verticillata* are alike in their vegetative parts and have similar adaptations. The three-species of plants, namely *Euphorbia antiquorum*, *Opuntia Dillenii* and *Boucerosia umbellata* growing in very dry situations and belonging to three distinct Families have the same type of vegetative shoots. The same kind of structural modifications caused by a set of ecological factors, in diverse species of plants, genealogically wide apart, is generally termed a growth-form. For ecological classification growth-forms may be taken as units. The growth-forms seen in *Euphorbia antiquorum* and *Boucerosia umbellata* are quite characteristic of plants growing in very dry places. Based on the availability of water, plants are broadly classified into Hydrophytes, Xerophytes and Mesophytes.

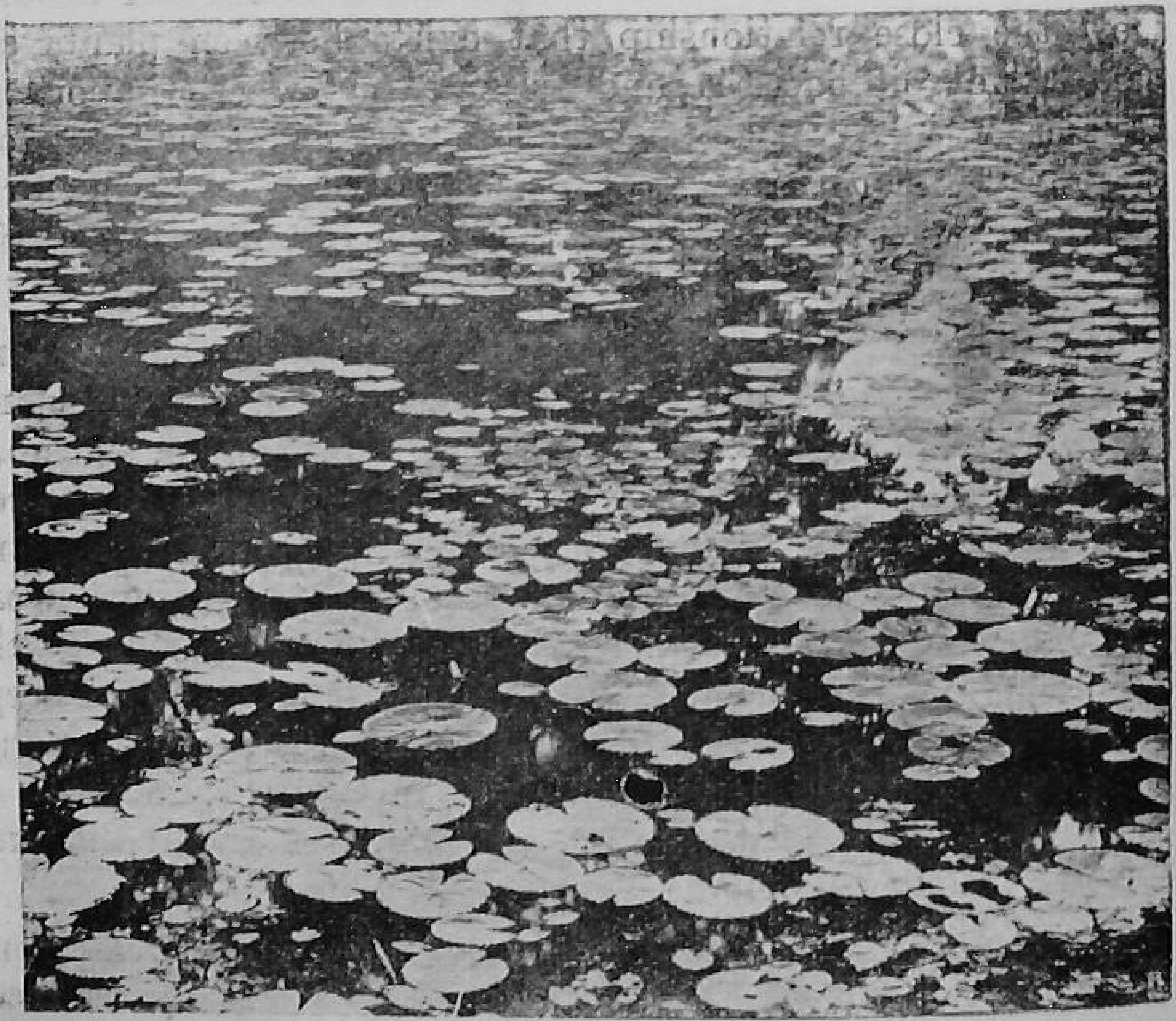

Fig. 399.—*Nymphaea pubescens.* A floating aquatic plant.

ECOLOGICAL GROUPS

Hydrophytes.—From the very name one can understand that hydrophytes are plants which live under conditions where there is abundance of water. There are those which are in a complete medium of water and there are still others growing in soil saturated with water. Plants may be completely submerged and rooted as in *Vallisneria spiralis*, *Ottelia alismoides* partly floating and attached as in *Nelumbium*, *Nymphaea* or free floating as in *Pistia*, *Wollfia*, *Spirogyra*, etc. There are others submerged and floating but not rooted such as *Utricularia*, *Hydrilla*, etc. Aquatic plants are very delicate and lack development of xylem and phloem. The latter are very poorly developed because of the fact the entire body absorbs water. What they are in need

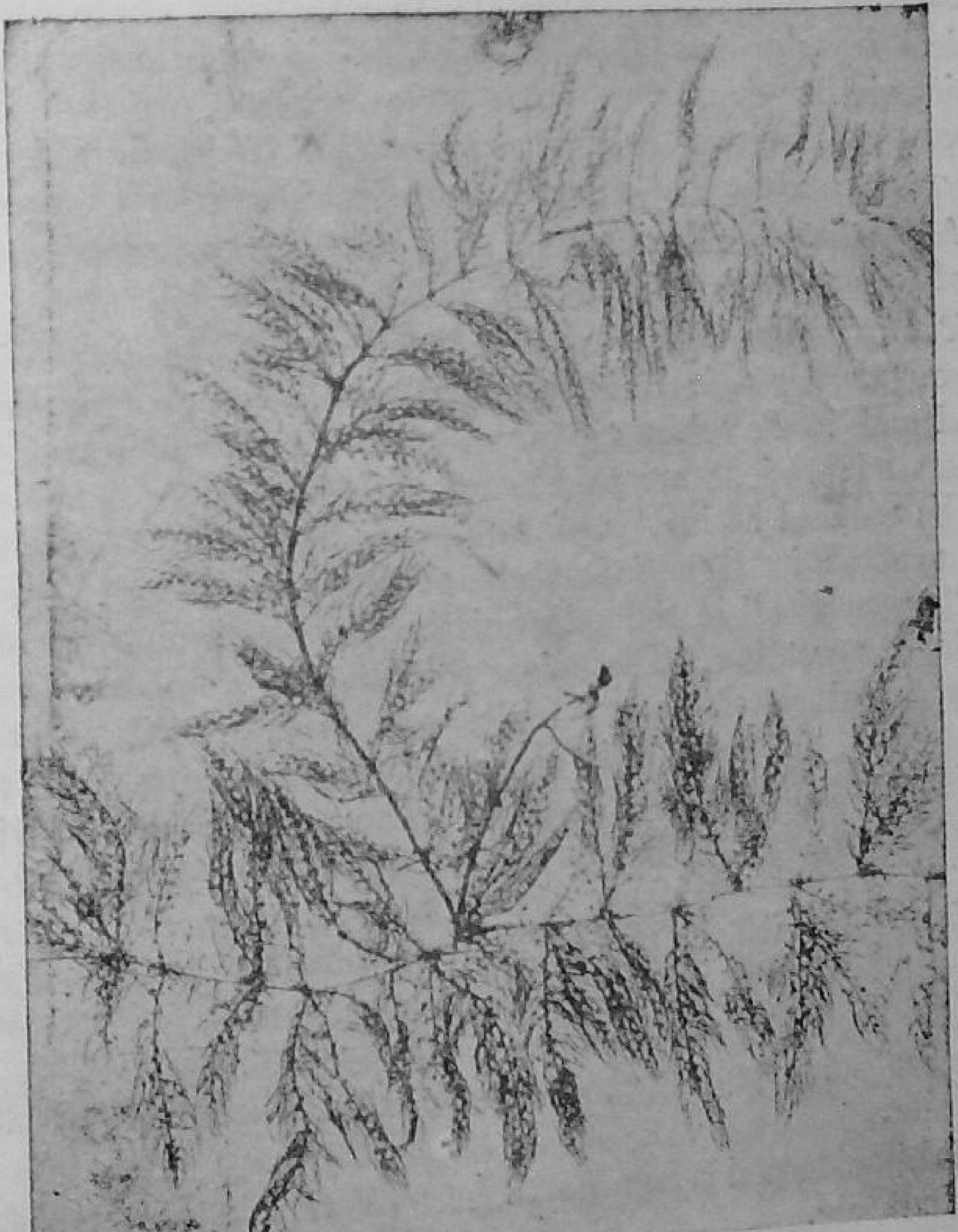

Fig. 400.—*Utricularia flexuosa*. The black dots seen in the leaves are all bladders.

of is really air and as such there is great provision made for this in the body of the plant. A cross section of the petiole of *Nymphaea* or *Nelumbium* will reveal the large air space. The amphibious hydrophytes can live not only in a complete surrounding of water, but also under terrestrial conditions when there is enough water in the soil, *e.g.*, *Typha*, *Polygonum*, *Panicum repens*, etc. These have rhizomiferous stems and possess plenty of sclerenchyma which makes them fit for aerial life. In them we see more of vascular tissues (xylem and phloem) which are poorly developed in true aquatics.

Xerophytes.—While hydrophytes form the characteristic vegetation of places where water is abundant, xerophytes characterise the other extreme, namely, situations which are very dry and lack water. There are two kinds of xerophytes, namely, (1) the true xerophytes which live in situations where there is physical drought, and (2) those which live in situations which are physiologically dry, *e.g.*, saline areas. These are known as *Halophytes*. In very cold situations water freezes into ice and under such conditions also the plants suffer a physiological drought.

Adaptations in Xerophytes :—These are (1) towards reducing loss of water due to transpiration and (2) storage of water.

The roots are often very long and penetrate to great depths for example, *Opuntia* (Prickly pear) has a large area or surface spread and in *Portulaca tuberosa* the roots are tuberous. The greatest adaptations are to be met with in leaves. The leaves may be reduced as in *Commiphora*, *Casuarina* and *Asparagus* or deciduous as in *Opuntia* and *Euphorbia tirucalli*. In grasses the "*motor cells*" in the epidermis help in the rolling up of the leaf in dry weather. The epidermal layer in all these cases is highly cutinised, often coated with wax or resin as in *Agave* or *Aloe*. There are scales as in many Malvaceous plants. All these are devices to check transpiration. The stomata are restricted in number and are protected by hairs or waxy bloom, or they may occur at the bottom of urn shaped hollows as in *Nerium*. The stem is woody with the maximum development of fibres and other mechanical tissues. Bark and cork development are permanent and thus check transpiration.

Succulent types, e.g., *Aloe*, *Agave*, *Euphorbia*, *Opuntia*, *Kalanchoe*.

Multi-epidermal layers are to be met with in *Ficus*, *Nerium*, groundnut, etc.

Halophytes :—Halophytes are plants growing in saline soil. The backwaters, the salt swamps and saline flats on both the East

and West coasts support a fairly large amount of vegetation. The land in close proximity to the sea and at the mouths of rivers and backwaters gets submerged daily by the tide and will be exposed only at low water. The soil in these situations consists of clay and sand saturated with water and reeking with foul odour on account of decaying organic matter. Even such a soil as this supports vegetation of a particular type, called '**Mangrove Formation.**'

The mangrove-vegetation is very common in muddy places where the water is calm. If these muddy swamps are extensive, the mangroves form a low forest. The trees are mostly low with countless arched aerial roots. In places, where there is deep water, species of *Rhizophora* grow, as they can fix themselves firmly in deep water. *Avicennia officinalis*, *Brugiera conjugata* and *Aegiceras corniculatum* occupy the shallow places and somewhat dry ground. As the mud in which these plants are growing is soft, fixation is a difficult matter. So in all these trees and shrubs, crooked, arched prop-roots are freely formed. The prop-roots and their tendency to go deep help the mangrove-plants to resist the bending that may be caused by winds and waves.

The soil is always water-logged and poor in oxygen and so respiration is a matter of difficulty. The submerged parts have large air spaces, and these intercellular cavities are in communication with large stomata and particularly large lenticels. Special respiratory roots also are developed in some species. In *Rhizophora* the prop-roots serve as **respiratory roots.** The respiratory roots are particularly well developed in the roots of *Avicennia*. The **pneumatophores (respiratory roots)** are erect about a foot or more in length, and stand in radiating rows all around the tree. From the vertical roots the position and direction of the underground normal horizontal roots may be inferred.

As the water is rich in salts, free absorption of water by the roots is out of the question. These plants take up water only in small quantities. Hence they must also have adaptations to prevent undue evaporation. So, in spite of the abundance of water, these plants have in their shoots structural features characteristic of xerophytes. The leaves of many of the mangrove-plants are thick, coriaceous, fleshy and the epidermis is strongly cuticularised. The chlorenchyma of the leaves consists mainly of palisade parenchyma without intercellular spaces.

Vivipary, or the germination of the embryo and its development into a seedling within the fruit, while it is still attached to

the parent plant, is a normal condition in many mangrove-plants. In *Brugiera* and *Rhizophora* the embryo grows out of the fruit and remains attached until it develops into fairly large seedling with club-shaped root-end. The seedling when formed and ready to drop down into the mud, consists of a club-shaped radicle with lateral roots and a hypocotyl with a short shoot. When the seedling detaches itself it is fairly large and the club-shaped and the pointed end of the radicle enables it to pierce the mud. If the seedlings happen to fall on water, they float and get stuck in holes at the earliest opportunity.

The fruits and seeds of many of these plants of mangrove swamps have special devices to enable them to float. The fruits abound in air-containing spaces and the germinating capacity of the seeds does not get impaired by the salt water. The *littoral* plants have a very wide distribution and the mangrove swamps have more or less the same species all long the sea-coast throughout the world. This is because of the uniformity of the medium and the temperature existing in the coast.

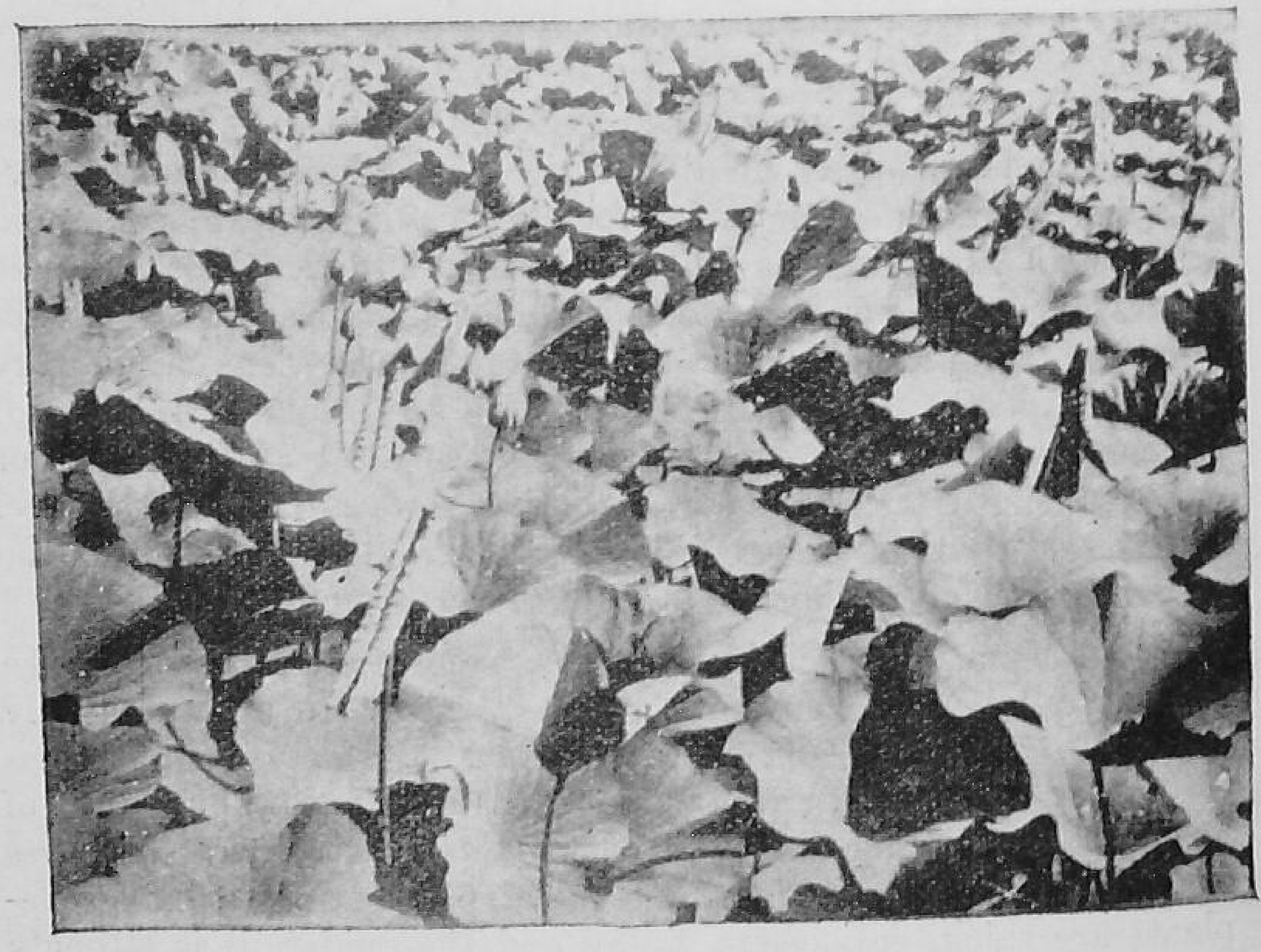

Fig. 401.—*Nelumbium speciosum.* An aquatic plant with leaves elevated above the surface of water.

Close to the mangrove swamps on the land side, we meet with shallow water and flats with mud, moist or dry. The plant

Acanthus ilicifolius grows in abundance in shallow places. Here and there we find *Pandanus* lifting its head from amidst *Acanthus*. Further away in flats that are distinctly saline we meet with several species of *Suaeda*, *Salicornia*, *Sesuvium*, *Portulacastrum* and *Heliotropium curassavicum*. All these plants are either herbs or shurbs with pronounced succulence, a characteristic of certain xerophytes.

As we recede towards the interior, we find sandy soil with sand-dunes. Sand being loose, the amount of water that it can retain is small. The loose nature of sand does not permit the rise of water from the sub-soil to any appreciable extent. On account of its being exposed to the heat of the sun and to wind, the sand gets heated rapidly and becomes dry very quickly. So plants fitted to thrive in the sandy soil assume characteristic growth-forms. The vegetation flourishing on this sand is usually much open. It consists of perennial plants with deep-seated, freely branching rhizomes bearing exceedingly long roots. All the plants display the xerophytic characters to a marked degree. The flora consists of species, such as *Cyperus arenarius*, *Launaea pinnatifida*, *Spinifex squarrossus*, *Ipomoea Pes-caprae*, *Hydrophylax maritima*, *Calotropis gigantea* and *Pupalia orbiculata*. Towards the interior this gradually gets merged into the ordinary scrub-flora.

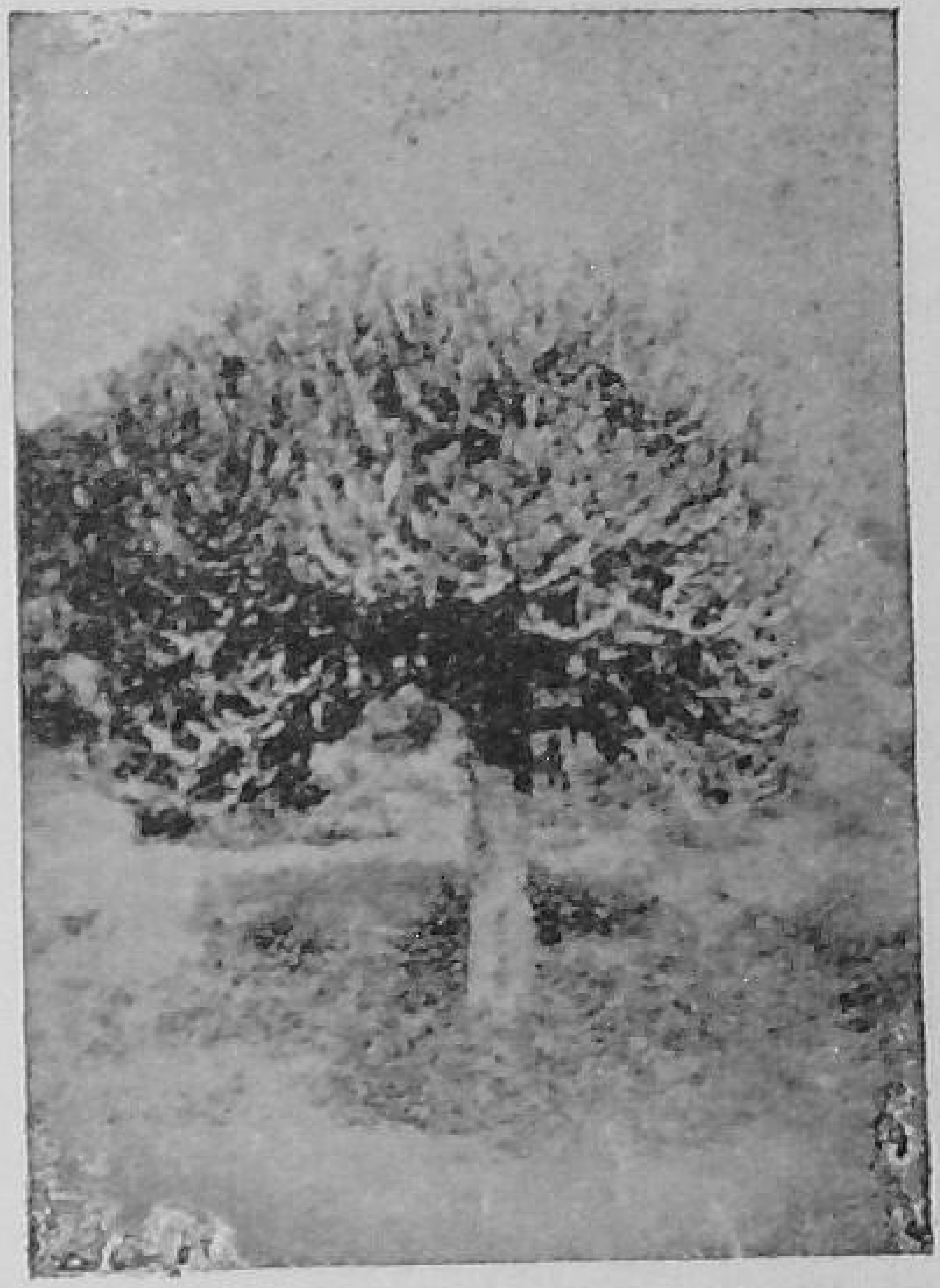

Fig. 402.—*Euphorbia antiquorum*. A fleshy xerophyte.

Lastly, we have one more group of plants that are peculiar in their mode of life, namely, the **Epiphytes.** All epiphytes attach themselves to other plants by means of aerial roots, but without abstracting any food from the latter. Attachment is only for fixation and support. Because of their unusual position they cannot obtain the nutriment and water easily. But they have managed to overcome this difficulty in a variety of ways. For

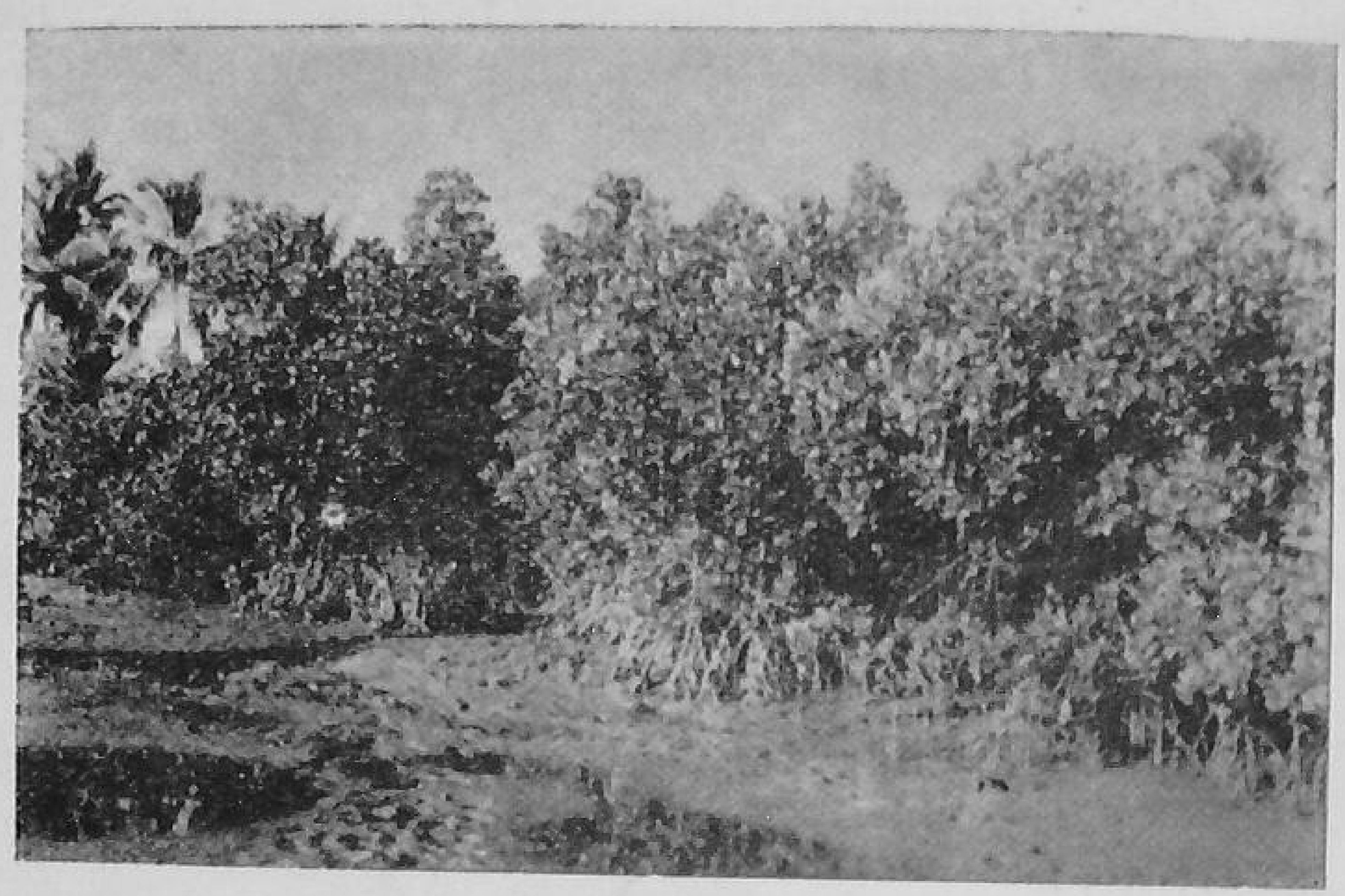

Fig. 403.—Mangrove plants. *Rhizophora.*

example, many of the epiphytic orchids and aroids growing in South India possess aerial roots specially adapted to the absorption of water. These aerial roots are white in appearance owing to the formation of a kind of sheath consisting of several layers of empty cells strengthened with thickenings here and there. This sheath is called **velamen** and it acts as a sort of sponge in absorbing water rapidly, whenever there is rain. Since epiphytes have to endure prolonged droughts like land xerophytes, certain structural features, distinctly xerophytic, are found in these plants. Most of the epiphytic orchids have fleshy **pseudobulbs,** and in some, the leaves are thick and fleshy. Arrangement for storage of water is also a necessity, as the sources of supply of water for epiphytes are dew, mist, or rain. The supply of water is precarious and it is possible only at long or short intervals. So these plants also have arrangement to prevent the loss of water.

From what is said above, it is obvious that epiphytes cannot live in places where the climate is very dry, but they can live where the atmosphere is likely to be humid at least for some months. On the East coast of South India we do not find many epiphytes but, on the other hand, they are found in profusion on the West coast, because humidity is greater and of longer duration in this coast than on the East coast.

Epiphytes should not be confused with parasites. There are the stem parasites like the *Loranthus* and the *Viscum* which are

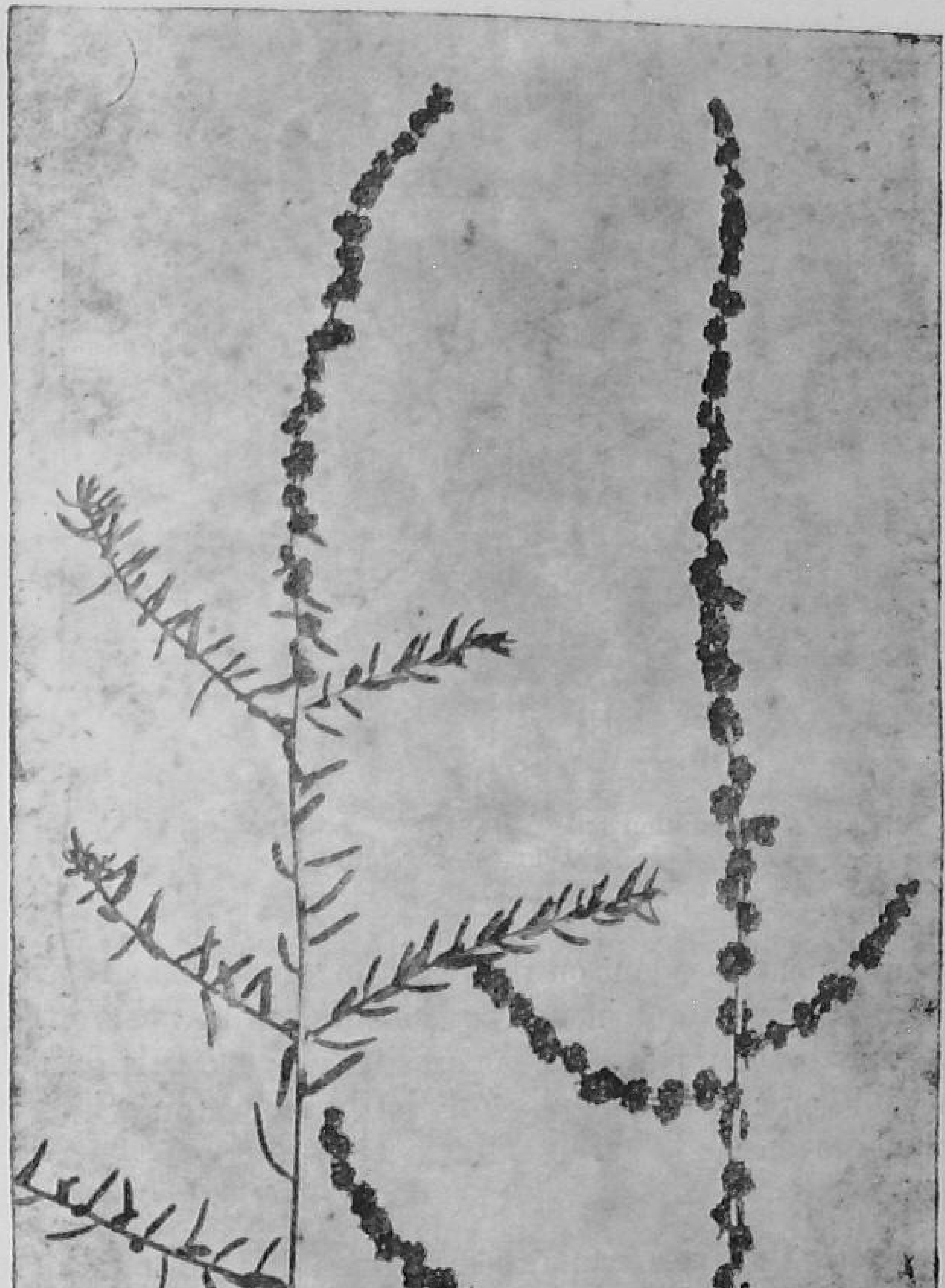

Fig.404.—A *Suaeda* plant with terete fleshy leaves.

found attached to the stems of branches of trees. These should not be mistaken for Epiphytes. There are as many as 20 species of *Loranthus* and 9 species of *Viscum* commonly met with in this province. These are found parasitising a number of trees, especially *Loranthus* on mango, pomegranate, etc. These are easily distinguished as parasites because of the *haustoria* (modified roots) by means of which they are not only firmly attached to the host but get their food. An Epiphyte like *Vanda* lacks such haustoria

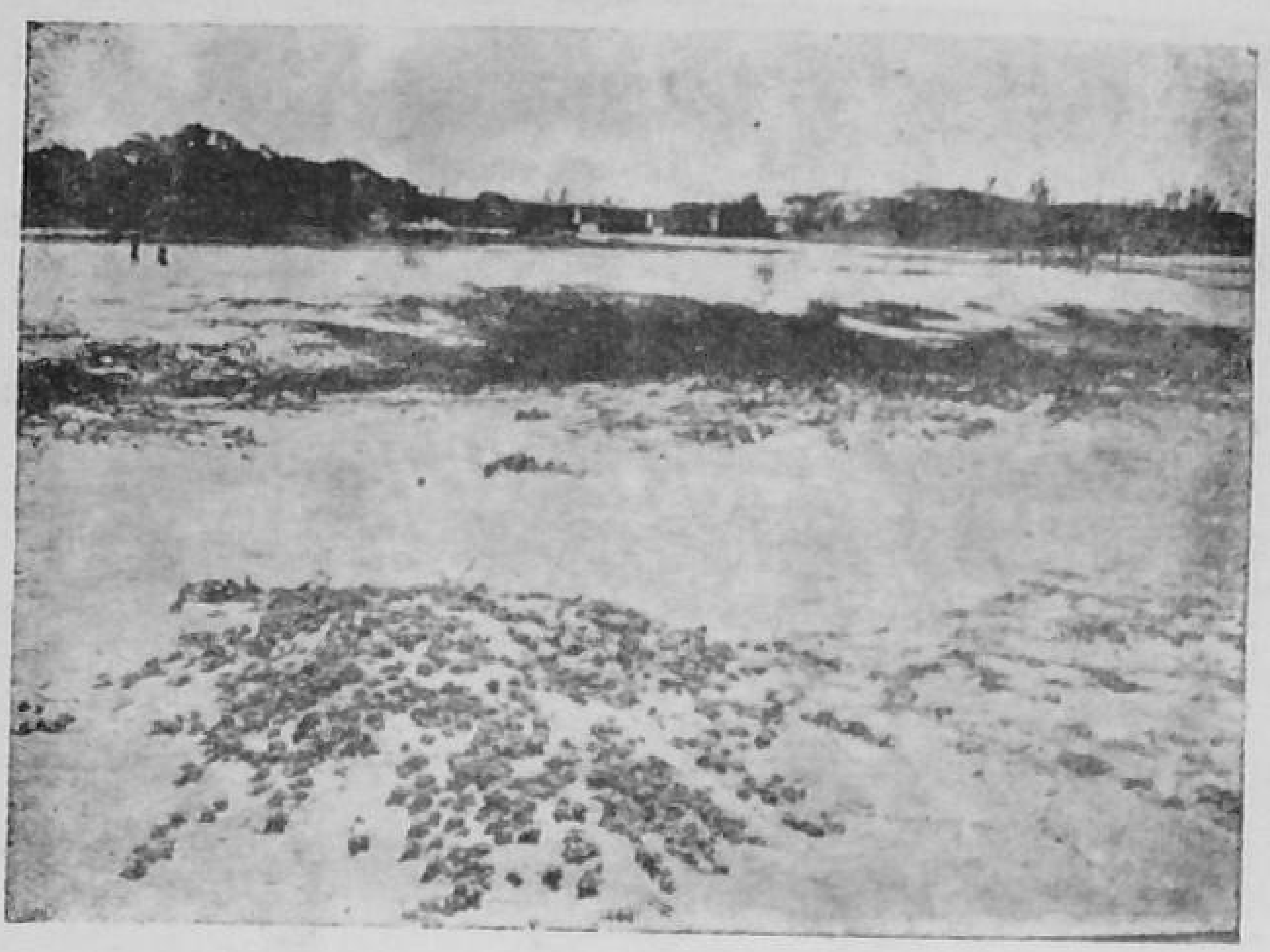

Fig. 405.—Vegetation on sandy soil. *Hydrophylax* in the foreground and *Ipomoea* in the background.

because it is not dependant on the plant on which it is growing for its food. Epiphytes are in no way harmful unless there are too many epiphytes on a plant. But parasites are as a rule dangerous and should be removed carefully off the branches on which they are found growing.

Generally epiphytes retain their mode of life throughout their life-cycle. But a few adopt the epiphytic mode of life only in the beginning and later on, their roots enter the ground and become ordinary land roots. *Ficus bengalensis* begins its life as an epiphyte, but when it grows large the aerial roots penetrate the soil and become supporting roots. The prop-roots help this tree to extend and occupy large areas.

The vegetation of South India is most varied and interesting. Thick forests with tall trees are confined to the higher hills of the Western Ghats. The Deccan-plateau supports scrub jungles and deciduous forests. In the sea coast in the sand we find sand-binding Xerophytic plants such as *Spinifex squarrossus*, *Ipomoea Pescaprae*, and *Hydrophylax*. This is succeeded by the mangrove swamps in which "mangrove-formation" thrives at its best.

Fig. 406.—*Spinifex squarrosus*, growing in sand.

Hoe & Co., Madras.

APPENDIX

Botanical name	Popular name	Tamil	Malayalam	Telugu
A				
Abrus precatorius	Crab's Eye	Kundumani	Kunni	Guruginja
Abutilon indicum	..	Thuthi	Uram	Thutiribenda
Acacica arabica	Babul	Karuvelam	Karuvel	Nallatumma
A. concinna	Rita Soap pod	Seekai	Cheenika	Seekaya
A. farnesiana	Cassie flower	Pee velam	..	Kampa tumma
A. leucophloea	..	Vel velam	Vel velam	Tella tumma
A. planifrons	Umbrella thorn	Kodai velam	..	Budda tumma
Acalypha indica	..	Kuppai meni	Kuppa meni	Kuppinta or Muripindi
Acanthospermum hispidum	..	Mul thulasi	Kattu nerinjil	..
Achras sapota	Sapodilla plum	Sapota	Sapota	Sapota
Achyranthes aspera	..	Nayuruvi	Kadaladi	Attaroni
Acorus calamus	Sweet flag	Vasambu	Vayambu	Vasa
Aegle Marmelos	Bael tree	Bilvam or vilvam	Koovalam	Bilvamu or Maredu
Aerva javanica	..	Periya poolai koorai	..	Peddapindikonda
A. lanata	..	Poolai	Cherupula	Pindi chettu
Aeschynomene aspera	Sola Pith	Netti	..	Jiluga
Agaricus campestris	Mush-room	Naikkodai	..	Kukka godugu
Agave americana	Railway aloe	Rail kathalai	Seema kathalai	Bontharakasi or Kitha Kithanara
Ailanthus excelsa	..	Pimaram	Peenari	Peddamaram
Albizzia Lebbeck	The Siris tree	Vaghai	Vaka	Dirisana
Allium cepa	Onion	Vengayam	Chuvannulli	Yerragadda
A. sativum	Garlic	Vellaipoondu	Velludi	Tellagadda
Allophyllus serratus	..	Amalai	..	Ervalu

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Botanical name	Popular name	Tamil	Malayalam	Telugu
A—*contd.*				
Alstonia scholaris	Shaitan wood	Elalaipalai	Ezhilapala	Yedakulapala
Alternanthera echinata	Khaki weed	Mull Ponnankanni	..	Mullu Ponagantikura
A. sessilis	..	Ponnankanni keerai	Kozhuppa	Ponagantikura
Amaranthus gangeticus	..	Thandukeerai..	..	Kamulu or Dantu
A. spinosus	..	Mullukeerai	Mullan cheera	Mundla thotakura
A. viridis	..	Kuppaikeerai	..	Chilaka thotakura
Ammania baccifera	..	Neermul neruppu	Kallar vanchi	Agnivenda-paku
Amoora Rohituka	..	Vellakongu	Karagil	..
Amorphophallus campanulatus	Elephant Yam	Karakkaranai	Cinapavu	Thiya kandha
Anacardium occidentale	Cashew-nut	Munthiri	Parangimavu	Jidimamidi
Anisomeles indica	..	Erumattaipinari	Chedayan	..
Anogeissus latifolia	Axle wood	Vellanagai	Vellanava	Yelama
Anona cherimolia	Cherimoya	..	..	..
A. muricata	Soursop	Mullu sita	Mullanchakka	..
A. reticulata	Bullock's heart	Ram seetha	..	Ramasita
A. squamosa	Custard apple	Seetha	..	Seetha
Arachis hypogaea	Pea nut	Veerkadalai or Nilakadalai	Nilakadala	Veru sanaga
Areca catechu	Betel nut	Kamuku or Pakku	Adakka	Poka
Argemone mexicana	Mexican poppy	Karukkumathu	Ponnumathu	Datturi
Aristida setacea	..	Oosipillu	..	..
Aristolochia bracteata	..	Aduthinapalai	Aduthinappalai	Gadathigadaparagu
Artabotrys adoratissimus	..	Manoranjitham	..	Manoranjitham
Artocarpus hirsuta	Wild Jak	Anjili	Ainipilavu	..
A. incisa	Bread-fruit	Seemaipila	Kadapila or Bilathi chakka	Sada panasa
A. integrifolia	Jack fruit	Pila	Pila	Panasa

Asparagus racemosus	..	Thannirmuttankizhangu	Sathavalli	Challagadda or Sadavari
Avicennia officinalis	..	Kandal	Orei	Mada
Azadirachta indica	Margosa or Neem	Vembu	Veppu	Veppa
B				
Barleria prionites	..	Kattu kanagambaram	..	Mullu-gorinta
Bassia latifolia	..	Illuppai	Illuppa	Ippa
B. longifolia	Mahua	Nattu iluppai	..	Ippai
Bauhinia tomentosa	..	Tiruvatti	Mandaram	Adavimandara
Benincasa Cerifera	Ash gourd	Kalyanapusani	Elavan	Pulla gummudi
Beta vulgaris	Beet-root	..	..	..
Boerhavia repens	..	Mukkaratai	Thamizhama	Punarnaba
Bombax malabaricum	Silk-cotton Red	Mullilavam	Pula or ilavam	Londabuarga
Borrasus flabellifer	Palymra	Panai	Karimpana	Thadi
Borreira hispida	..	Nathachuri	Konal churukki	Zadana Budama
Brassica juncea	Red Mustard	Kadugu	..	Avalu
Bryophyllum calycinum	..	Ranakalli	..	Simajamudu
Buchanania angustifolia	Cudappah Almond	Kattu ma	Cheru	Sara
B. Lanzan	..	Saraipparuppu	Cheru	Sara
Butea frondosa	Flame of the forest	Palasam	Plas	Moduga
C				
Cadaba	..	Veludthu	..	..
Caesalpinia pulcherrima	Peacock flower	..	..	Pamidi tangedu
C. sepiaria	..	Putthadukki	Inna	Gooddakorinda
Cajanus cajan	Red gram	Thovarai	Tuvarai	Kandulu
Calamus rotang	Cane Palm	..	..	..
Calophyllum inophyllum	Alexandrian Laurel	Punnai	Punna	Ponna
Calotropis gigantea	The madar	Erukku	Erukku	Jilledu
Canavalia ensiformis	Sword bean	Vaal avarai	Vaal avarai	Tumbattan kaya

Botanical name	Popular name	Tamil	Malayalam	Telugu
C—*contd.*				
Canna indica	Indian Shot	Kalvazhai	..	..
Cannabis sataiva	Hemp	Ganja	Kanchava	Ganja chettu
Capparis sepiaria	..	Thoratti	..	Nalluppi
Capsicum annuum	Chilly or red pepper	Mulagai	..	Mirapakaya
C. frutescens	Bird pepper	Oosi milagai	..	..
Cardiospermum halicacabum	Baloon vine	Modakkathan	Ulina	Buddakakkira
Carica papya	Papaw	Papali	Karutha or kaplam	Boppayi
Carissa carandas	Christ's thorn	Kilakkai	Klavu	Kalivi
Carthamus tinctorius	Safflower	Kusamba	..	Kusamba
Carum copticum	Ajwan	Asambadam or Omum	Ayamodakam	Omamu
Cassia auriculata	Tanner's Cassia	Avaram	Avaram	Tangedu
C. obovata	Senna	..	..	..
C. siamea	..	Manjakkonnai	..	Sima tangedu
Casuarina	The Tinnian Pine	Savukku	Chulamaram	Saravu
Cedrela Toona	Red Ceder, the Toon	Malavembu	Chuvannagil	Galimanu
Celosia argentea	..	Pannai keerai	Kozhipullu	..
Cenchrus ciliaris	..	Kolukattai pullu	..	..
Chenopodium album	..	Parupu or chakravarthi keerai	..	..
Chloroxylon swietenia	East Indian Satin Wood	Vaimaram	..	Billudu
Chrozophora Rottleri	..	..	..	Gurugu ; Lingam miriyalu
Chukrasia tabularis	..	Madagirivembu	Chuvannagil	..
Cicer arietinum	Chick pea or Bengal gram	Kadalai	Kadalai	Sanikalu
Cinchona officinalis C. succirubra	Quinine Tree	Koyina	Koyina	Javarapatta
Cinnamomum zeylanicum	Cinnamom	Lavangam	Lavangam	..

Cipadessa baccifera	..	Savattucheddi	..	Chedubira
Cissampelos pareira	..	Appatta	Pata	Pata
Cissus quadrangularis	..	Perandai	Changaiparanda	Nalleru
Citrullus colocynthis	Bitter apple	Pey kummatti	..	Patsakaya
Citrus aurantifolia	Lime	Elimichcham	Cherunaranga	Nimmapandu
C. aurantium	Lime-orange	..	..	..
C. decumana	Pomello	Bomblimas	..	Bobblimas
C. limonia	Rough lemon	..	..	..
C. medica	Citron	Narthangai	Vadugapuli	..
C. nobilis	Loose jacket	Kamala	Kamala	..
C. sinensis	Tight Jacket	Sathgudi	..	Cheeni
Clematis smilacifolia	..	..	..	Peddutivva
Cleome viscosa	Wild mustard	Nai kadugu	Nai kadugu	Kukka vavinta
Clerodendron inerme	..	Pinchil or Sangam kuppi	..	Pisungi
C. phlomoides	..	Sangum	..	Telaki
Clitorea ternatea	..	Kakkatan	Sankapushpam	Sangapushpam
Coccinea indica	..	Kovai	Kova	Kakidonda
Cocculus	..	Kattukodi	..	Dusaratiga
Cochlospermum gossypium	..	Odiya	Seemapanji	Kondagogu
Cocos nucifera	Coconut	Thennai maram	Thengu	Tenkaya
Coix Lachryma-Jobi	Job's tears	Kattu kundumani	..	..
Coffea arabica	Coffee	Kappi	Kappi	Kappi
C. robusta	Coffee	Kappi	Kappi	Kappi
Colocasia antiquorum	Taro	Kattuseenai	Kattuchena	Chema
Combretum	..	Odankodi	Pullani	Yedatiga
Commiphora Berryi	..	Mulkiluvai	..	..
Convolvulus arvensis	Field bind weed	Bhoomichakrapondu	..	..
Corchorus capsularis	Jute	Sannai or perum punaku poondu	..	Janumu or Perinta-koora
C. olitorius	Jute	Sannai or perum punaku poondu	..	..
C. trilocularis	..	Punaku poondu	..	..
Cordia myxa	..	Naruveli	Viri	Iriki

Botanical name	Popular name	Tamil	Malayalam	Telugu
C—*contd.*				
Coriandrum sativum	Coriander	Kottamalli	..	Dhaniyalu
Crataeva religiosa	..	Mavalingam	Niramathalam	Voolemeri
Crinum asiaticum	..	Visha moongil	..	..
Crotalaria juncea	Sunn hemp	Sanappai	Vakku	Jannamu
C. retusa	..	Peechalankai	Kilukilukkai	..
C. verrucosa	..	Gilugiluppai	..	..
Cucumis trigonus	..	Thummattikai	..	Budamakaya
Cucurbita maxima	Pumpkin	Parangi	Maththan	Pedda gummedi
C. pepo	Vegetable marrow	Seemai poosani	..	..
Curcuma longa	Turmeric	Manjal	Kuva	Pasupu
Cuscuta reflexa	..	..	..	Sithmansavaram
Cyanotis cucullata	..	Nayini poondu	..	Amadakaya
Cynodon dactylon	Hariali	Arugampillu	Karuka pul	Gericha gaddi
Cyperus bulbosus	Bulb grass	Shilandi	..	Pura gaddi
C. rotundus	Nut grass	Korai kizhangu	Kora	Saka tunga gaddi
D				
Dactyloctenium aegyptium	..	Mattangapillu	..	..
Daemia extensa	..	Sindalkodi or Vedi paruthi	..	..
Dalbergia latifolia	Indian Rose-wood	Itti or Thodagatti	Veeti or Itti	Jittegi
D. sissoides	Black wood	..	Veeti	..
Datura fastuosa	Thorn apple	Umathan	Ummatham	Ummatha
Debregeasia velutina	Wild Rhea	Kattu nochi	..	..
Delonix regia	Gulmohr	Mayil konnai	Alasippu	Erraturayi
Derris scandens	..	Punali	..	Chirattaliboddu
Desmodium triflorum	..	Nilamparanda	Cherupulladi	..
Dicanthium annulatum	..	..	..	Molavagaddi

ichrostachys cinerea	..	Vattathari	..	Veluturu
Digera arvensis	..	Thoyyakkirai	..	Chenchali koora
Dioscorea pentaphylla	Fiji yam	Kattu valli	..	Adavi gummaditiga
Dodonaea viscosa	..	Virali or Valari	..	Bandari
Dolichandrone falcata	..	Chitthaththi	..	Chittodi
Dolichos Lablab	..	Avarai or Mochai	..	Chikkudi or Anapa
E				
Echinochloa colona var frumentacea	Japanese Barn yard-millet	Kudiravali	..	Oddalu
Eclipta alba	..	Karisarangani	Koyonni	Guntakalawaraka
Ehretia buxifolia	..	Kodikarai	..	Bupanaburi
Eichhornea crassipes	Water hyacinth	Pisasuthamarai	Kola vazha	Anthara thamara
Elephantopus scaber	..	Anauichuvadi	..	..
Eletarria cardamomum	Cardamum	Elam	..	Elakkulu
Eleusine aegyptiaca	..	Mattangapillu	..	..
E. coracana	Finger millet	Kevaru or Ragi	Ragi or Muthari	Ragi
Entada scandens	..	Cillu	Kakkavalli	Gillatige
Eridodendron pentandrum	Silk Cotton White	Illavam	Seema poola	Buruga
Eucalyptus Globulus	Eucalyptus	Karpuramaram	..	..
Eugenia jambolana	Indian Cherry	Naaval	Naaval	Neeredu
Euphorbia antiquorum	..	Chadurakkalli	..	Bonthakali or Peddajamudu
E. hirta	..	Ammampacharisi	..	Nanabalu
E. rosea and E. thymifolia	..	Chinnammampacharisi	Chitrapala	..
E. tirucalli	..	Tirugukkalli	..	Jamudu
Evolvulus alsinoides	..	Vishnukirandi	Vistnaclandi	Vishnukranthi
F				
Feronia Elephantum	Wood apple	Vila	Mlanka	Velanga
Ficus asperrima	..	Pechi or Pethi	..	Karakabodda
F. bengalensis	Banyan	Alam	Peral	Marri

Botanical name	Popular name	Tamil	Malayalam	Telugu
F—*contd.*				
F. elastica	Indian Rubber			
F. glomerata	Country Fig	Aththi	Aththi	Bodda
F. religiosa	Sacred peepul	Arasu	Araial	Aswatham or Ravi
Filicium decipiens		Athadalai	Niroli or kattunelli	
G				
Garcinia cambogia		Korukapuli	Mampulichi or kodapuli	
G. indica			Kodampuli	
G. Mangostana	Mangosteen			
G. Morella		Makki	Chigiri	
Givotia Rottleriformis		Velthadai		Tellapoliki
Gloriosa superba		Kalappaikkizhangu	Kithonni	Agnisika
Glycine Max	Soy bean			
Gmelina asiatica		Mulkumil		Kavvagu
Gomphrena decumbens		Neervadamalli		Neerubogadabanti
Gossypium arboreum var neglectum forma indica	Karunganni Cotton	Karunganni paruthi		
G. arboreum var typicum	Nadam ,,	Nadan paruthi		
G. herbachum frutescens	Uppam ,,			
G. hirsutum	Camodia ,,			
G. purpurascens	Bourbon ,,			
Grangia maderaspatana		Nilampala		Mustaru
Grewia tiliaefolia		Thadachi	Chadachi	Peddajana
Guazuma tomentosa		Thenmaram		Rudraksha
Guizotia abyssinica	Niger	Peyellu		Valiselu
Gymnosporia montana		Kattangi		Danti
Gynandropsis pentaphylla		Nai velai or Kattu kadugu	Karvela	Vaminta
Grpacoyrus jacquini		Tanuku		Poliki or Tanuku

H				
Hardwickia binata		Acha	Acha	Yepi
Helianthes annus	Sun flower	Suriyakantni		Suriyakanthi
H. tuberosus	Jerusalem artichoke			
Helictres isora		Valambiri	Kayyuna	Adavi chamanthi
Heliotropium indicum		Thel-koddukku	Thenkkada	
Hemidesmus indicus	Sarasaparilla	Nannari		Sugandipala
Hibiscus cannabinus	Deccan Hemp	Pulichai or Kachurakkai		Gogu
H. esculentus	Lady's fingers	Vendai		Benda
H. ficulneus		Kattu bendai		Nalla benda
H. micranthus		Kurivippoondu		Nityamalli
H. Rosa-sinensis	Shoe-flower	Sappaththi or Shen-paruthan		Dasani or Mandara
H. vitifolius		Manithuthi		Karupathi
Holoptelia integrifolia	Indian Elm	Ayili or thavani	Aval	Tapasi
Hopea parviflora	Iron wood of Malabar.	Vellai kongu	Irumbagam	
Hydrilla verticill‑ ‑a		Velampasi		
Hygrophila spinosa		Neermulli		
I				
Indigofera enneaphylla		Seruppu nerinji	Cheruppulladi	Yerrapallera
I. sumatrana	} Indigo	Aviri or Neelam	Amari	Aviri or Needi
I. tinctoria	} Indigo			
I. trita		Kakka Naru		
Ionidium suffruticosum		Orilaithamarai	Orilathamara	Ratna-purusha
Ipomoea batatas	Sweet-potato	Sakkaraivallikkizhangu	Sakkarakizhangu	Genusu
I. biloba		Musalkathukeerai		
I. bona-nox		Mookuthikkai		
I. sepiaria		Thalikeerai	Tiru-tali	Metta-tooti
Ixora coccinea		Koranpoo	Thechi	
I. parviflora	The torch tree	Sulandu		Gorivi

Botanical name	Popular name	Tamil	Malayalam	Telugu
J				
Jambosa vulgaris			Champa	Gulabjama
Jasminum angustifolium		Kattumalligai		
J. sambac	Jasmine	Kodimalli		
Jatropha curcas		Kattamanakku	Kattuvamanakku	Adavi amudam
Juglan regia	Walnut			
Jussieua		Nir-kirambu		
Jsticia tranquebariensis		Sivanarvembu		
L				
Lagerstroemia Flos-reginae		Pumaruthu	Nirventekku	
L. lanceolata		Ventekku	Ventekku	Chennagi
Lantana aculeata	Wild sage	Arippu	Puchedi	Lantana
Lawsonia inermis		Maruthani	Mylanji	Gorinta
Leptadenia reticulata		Paalai kodi		Pala tige
Leucas aspera		Thumbai	Thumba	Tamma chettu
Linum usitatissimum	Linseed	Aali virai		Avisi
Lippia nodiflora		Poduthalai	Kattu-thippilli	Gajapippala-kada
Lochnera pusilla		Milagaipoondu		
L. rosea		Pillayarpoo or Thuluk-kamalli		
Loranthus longifolius		Pulluruvi	Ithikanni	Bajiniki
Lycopersicum esculentum	Tomato	Seemai thakkali	Petakkali	Thakkali
M				
Mahonia leschenaultti		Mullukadamtu		
Mangifera indica	Mango	Mamaram	Mavu	Mamidi
Marsilia coromandelica M. minuta		Arakkodai		Chicklitakura
Martynia diandra		Thelkodukkai or Puli-nagam	Pulinaham	Garuda mukku

Melia Azedarach	Margosa	Veppamaram	Veppu	Vepa
Mesua ferrea	Iron wood	Nangul	Cheruli	Nagakesari
Michelia champaca	Champac	Shanbagam	Chembagam	Sampaka
M. nilagirica	..	Kattushanbagam	Do.	..
Millingtonia hortensis	Indian cork tree	Maramalligai	..	Manumalli
Mimosa pudica	Touch-me-not	Thottasiningi	Thotta vaadi	Pedda nidrakantha
Mimusops Elengi	..	Mogidam or Maghizham.	Elengi	Pogada
M. hexandra	..	Palai	Do.	Pola
Mirabilis jalapa	Nightshade	Andimandarai	..	Chandrakanta
Mollugo lotoides	..	Siru seruppadi	..	Chadrasikoora
Momordica charantia	Bitter gourd	Paagal	..	Kakara
Moniera cuneifolia	..	Neerpirami	Beami	Sambrani mokka
Morinda tinctoria	..	Nuna	Manjapavatta	Maddi
Moringa Oleifera	Horse Radish or Drum stick	Murungai	Muringa	Munaga
Murraya exotica	China-box	Kattukariveppilai	Kattukaruveppu	Nagagolugi
M. koenigi	Curry leaf	Karuveppilai	Karuvepilai	Karepaku
Musa paradisiaca	Banana	Vazhai	Vazha	Arati
Myristica fragrans	Nutmeg	Jathikkai	..	Jajikaya
N				
Nelumbium speciosum	Lotus	Thamarai	..	Damara
Nerium odorum	Oleander	Arali	Kanaviram	Ganneru
Nicotiana Tabacum	Tobacco	Pugailai	..	Pogaku
Nyctanthes Arbor-tristis	Night-jasmine	Pavelam	Parijathakam or Pa-vazhamalli	Parijatham
Nymphaea pubescens	Water lily	Alli or ambal	..	..
O				
Ocimum Basilicum	Basil	Thirunitruppachchai	..	..
O. canum	..	Nai thulasi	Kattu thulasi	Kakka thulasi
O. sanctum	Sacred Basil	Thulasi	Thulasi	Oddhi or Gumpina

Botanical name	Popular name	Tamil	Malayalam	Telugu
O—*contd.*				
Odina wodier		Udayam	Annakara or Udi	Gumpini
Oldenlandia umbellata	Chay-root	Chayaver		Siriveru
Opuntia Dillenii	Prickly pear	Sappathikalli	Kalli mullu or Naga-mullu	Nagadali
Orobanche cernua		Pokayilai-kalan		Bodu
Oroxylum indicum		Palagaipayani	Vellapadiri	Pampini
Ottelia alismoides		Akasa thamarai or Kotti-kizhangupasi		
Oxalis corniculata		Puliyarai		
P				
Pandanus	Screw pine	Thazhai	Kaitha or Thazha	Mogil
Panicum Isachne				Domakulugaddi
P. miliaceum	French millet	Pani varagu		Varagi
P. miliare	Little millet	Samai		Sama
P. repens	Ginger-grass	Inji pillu		Karigaddi
Papaver somniferum	Opium			
Paspalum scrobiculatum		Varagu		Arika
Pavetta indica		Pavattai	Pavatta	Papiti
Pavonia zeylanica		Sitha mutti		Chinna Mudda-pulagam.
Pemphis acidula		Keeri		
Pennisetum typhoides	Pearl milet	Cumbu		Sajja
Phaseolus lunatus	Lima bean			
P. Mungo	Black gram	Ulundu	Uzhunnu	Uddulu
P. radiatus	Green gram	Pasi payaru	Cheru payaru	Pesalu
P. trilobus		Narippayaru	Cheruvidukol	Pilli-pesara
Phoenix sylvestris	Wild date	Ichcham	Itta	Itha
Phyllanthus emblica		Nelli	Nelli	Usiri
P. maderaspatensis		Melanelli		Nelausiri
P. reticulata		Pula		Nallapurugudu
Physalis minima		Siruthakali	Njodi-njotta	Budamakaya
Piper betle	Betel leaf	Vettilai		Tamalapaku

P. cubeba	Cubeb	Thippili	Thippili	
P. nigrum	Black pepper	Milagu	Karumulagu	Savyamu
Pisonia		Lachchakattai or Thovi-dialkeerai		
Pistia stratiotes		Akasa thamarai		
Pisum sativum	Garden pea	Pattani		
Pithecolobium dulce	Madras thorn	Kodukkappalli		Seema chinta
Plectronia parviflora		Karai		Balasu
Polyalthia longifolia		Asoku or Nettlingam	Nedunar or Arana	Asokamu
Polyanthes tuberosa		Nila sampangi		Sukandaraji
Pongamia glabra		Pungam	Ungu or Pongu	Kanuga
Portulaca oleracea		Pasarai	Karie cheera	Pedda pavili kura
P. quadrifida		Sirupasarai	Neela keera	Gorri geddam
Prunus domestica	Juliana plum			
P. persica	Peach			
Psidium Guajava	Guava	Koyya	Alakkapazham	Jama
Pterocarpus Marsupium	The Kino tree	Vengai	Venga	Yegisi
P. santalinus	Rose-wood	Chemmram	Raktachandanam	Yerra sandanam
Pterolobium indicum		Karu indu		Siki or Undra
Pupalia atropurpurea		Aadai otti		
Pyrus communis	Pear	Beri Kai		
P. malus	Apple			
Q				
Quisqualis indica	Rangoon creeper	Rangoon malli		
R				
Randia dumentorum		Marakalan	Kattakere	Marrga
Raphanus sativus	Radish	Mullangi	Mullanki	Mullangi
Rhizophora		Kandal		Kandla
Rhododendron nilagirium		Alingi	Kattupuvarasu	
Rhodomyrtus tomentosa	Hill gooseberry	Thavattukoyya		
Rhynchosia minima		Chitt-avarai		Geddi chikkudu
Ricinus communis	Castor	Amanakku	Aavanakku	Amidamu
Ruellia procumbens		Pottalanchi		
R. prostrata		Silandi nayagam		

Botanical name	Popular name	Tamil	Malayalam	Telugu
S				
Saccharum barberi	Thin cane	Karumbu	Karimba	Cheruku
S. officinarum	Thick or noble canes			
S. spontaneum	Wild cane	Naval Karumbu	..	..
Santalum album	Sandal wood	Sandanamaram	Chandanamaram	Srigandapu manu
Sapindus emarginatus	Soap nut	Punnankottai or Pungan-kottai	..	Kun Kati Kai
S. trifoliatus				
Schleichera trijuga	Ceylon oak	Puvathi	Puvam	Pulusarai
Scolopia crenata	..	Kodali maram	Charalu	..
Sechium edule	Chow-chow	Seemaikattiri	..	..
Semecarpus anacardium	Marking nut	Serankottai or Senkottai	Chera	Jidi
Sesamum orientale	Gingelly	Ellu	Ellu	Nuvvulu
Sesbania aculeata	Daincha	..	..	..
S. aegyptiaca	..	Sithagathi	..	Nallasomintha
S. grandiflora	..	Agathi	..	Avisi
Setaria glauca	..	Koralipullu	..	Nakkakoora
S. italica	Italian millet	Tenai	..	Korra
Sida spinosa	..	Kattu venthiyam	Kattu venthiyam	Teranalla benda
Solanum Melongena	Egg plant	Kaththiri	Vazhuthananga	Vanga or vankaya
S. nigrum	Black night shade	Manathakali	Mulaguthakali	Kamanchichettu
S. torvum	..	Nalla sundari	..	..
S. tuberosum	Potato	Urulaikkizhangu	Urulekkelangu	Urulagadda
S. xanthocarpum	..	Kandankathiri	Kandankathiri	Nelavakudu
Sonchus arvensis	..	..	..	Jangi tamaku
Sonneratia	..	..	..	Kandla
Soymida febrifuga	Indian red wood	Sombrupattai	..	Somi
Sphaeranthus indicus	..	Kottai karanthai	Adakka maniyan	Boda-saram
Spondias mangifera	Indian Hog plum	Kattu mavu	Ambazha	Adabi mamidi
Stachytarpheta indica	..	..	Kadaladi	..
Stemodia viscosa	..	..	..	Gunta kaminum
Sterculia foetida	..	Peenari	Anathondi	..
Strebulus asper	..	Pixayan	Kurinju	Baranika
Striga lutea	..	Pallipoondu	..	..

Synantherias sylvatica	..	Kattukkaranai	..	Adavikanda
Syzigium jambolanum	Indian cherry	Naval	Naaval	Neredu

T

Tamarindus indica	Tamarind	Puliyan	Puli	Chintha
Tectona grandis	Teak	Thekku	Thekku	Teku
Tephrosia purpurea	..	Kolingi	Kozhingil	Vempali
Terminalia Arjuna	..	Maruthu	Vellilavu	Tella madoi
T. catappa	Indian almond	Nattu vadumai	Adamaram	Badami
T. chebula	Myrobalans	Kadukkai	Kadukka	Karaka
T. paniculata	..	Pilla maruthu	Pilavumarudu	..
T. tomentosa	..	Kari maruthu	Karumarutha	Nalla maddi
Theobroma cacao	Cocoa or cacoa	..	..	..
Thespesia populnea	Portia tree	Poovarasu	..	Gangaravi or Gangarani
Thevetia neriifolia	Yellow oleander	Tirivachipoo or Thanga-arali	..	Pachaganneru
Tinospora cordifolia	..	Sindhil kodi	Amrita	Tippatiga
Toddalia asiatica	..	Milangarani	..	Kondakasinda
Tragia involucrata	Nettle	Kanjuri	Choriyanam	Pinna-doolagunda or Jal bichuti
Tragus biflorus	..	Ottrampillu	..	..
Trapa bispinosa	Water chestnut	Singarakottai	..	Paniphal or Singhara
Trewia nudiflora	..	Kumbala, Attarasu	Thavala	..
Trianthema decandra	..	Vella saranai	..	Tella galijeru
T. portulacastrum	..	Saranai	Pasali keera	Galikeru
T. triquetra	..	Sirusaranai	..	Kukkapala koora
Tribulus terrestris	..	Nerinji	Nerunjil	Palleru
Trichodesma indicum	..	Kazhuthai thumbi	..	..
Trichosanthes anguina	Snake gourd	Pudalai	Podalai	Potla
Tridax procumbens	..	Vettukayappoondu	..	..
Triumfetta rhomboidea	..	Mudappoondu	..	Banki tuthuri
Triticum vulgare	Wheat	Ghodumai	Kothampan	Gothi
Typhonium trilobatum	..	Karunkarunai	..	..

Botanical name	Popular name	Tamil	Malayalam	Telugu
U				
Urginea indica		Narivengayam		
V				
Vallisneria spiralis	Tape grass	Kuthiraivalempasi		
Vateria indica	Indian copal tree	Velliakundrikam	Vellapayini	
Ventilago maderaspatana		Vembadam	Vembadam	Surabhi
Vernonia cinerea		Neichitti chedi		Gariti kamma
Vicoa indica		Mookuthippoondu		
Vigna sinensis	Cow pea	Thattapayeru or Karamani		Alachandalu
Viscum		Ottu		
Vitex negundo		Nochi	Nochi	Vayala or Vavili
Vitis vinifera	Grape vine	Dhraksha	Dhraksha	Draksha
W				
Withania somnifera		Amukram kizhangu		Asvagandhi
Woodfordia fruticosa				Jaji
Wrightia tinctoria		Palai or Nilapalai	Pala ; thanthapala	Pala or Reppala
X				
Xanthium strumanium		Marul umathan		Marula mathangi
Xanthophyllum flavescens		Muttainarathai	Maddaku	
Xylia xylocarpa		Irul	Irumulla	Kondatangedu
Z				
Zea mays	Maize or corn	Makkacholam		Mohka jonna
Zingiber officinale	Ginger	Inji	Inchi	Allam
Zizyphus jujuba	Jujube tree	Ilandai	Elantha	Regu
Z. oenoplia		Soorai	Oguri	Banka
Z. xylopyrus		Kottai ilandai	Kotta mullu	Gotti

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